THE ECONOMICS OF WATER POWER DEVELOPMENT

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McGRAW-HILL BOOK COMPANY, INC.
NEW YORK 370 SEVENTH AVENUE
LONDON 6 & 8 BOUVERIE ST., E C 4

PREFACE

For many years the subject of water power development and utilization has been of interest to statesmen, engineers, economists, power companies, investors, and the public at large. The importance of power in modern industry is widely recognized, and the potential contribution of water power to the power supply has been the subject of much thought and survey. The value of this source of power, however, has frequently been overrated, and the costs of its development have not received careful study. In the present work the author has attempted to analyze the factors governing the economic exploitation of water power resources.

The material has been gathered from reports of the Federal Power Commission, the *Transactions of the World Power Conference,* the United States Geological Survey, reports of states, publications of technical societies, technical journals, principally the *Electrical World, Engineering News-Record,* the *Electric West, Power,* as well as many private reports.

The author expresses most grateful appreciation to Dr. Richard T. Ely, at whose suggestion this study was undertaken, and to Dr. E. W. Morehouse, of the Institute for Research in Land Economics and Public Utilities, Northwestern University, who read the entire manuscript and offered many valuable suggestions.

Walter H. Voskuil

Philadelphia, Pennsylvania, 1928

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I

WATER POWER AND THE POWER PROBLEM

Early importance of water power. The importance of power in modern life Extent of America's power resources. Public interest in water power utilization.

THE use of mechanical power in the manufacturing industries in this country dates back to the middle of the eighteenth century, when the New England colonists harnessed the waterfalls to turn the gristmills and sawmills, to card wool, and to operate small shops and factories. Although these hydraulic plants were small in size and limited in the scope of their use, nevertheless they influenced considerably the industrial development of New England and early placed that section of the country in the leadership as an industrial center. Indeed, the presence of water power had a marked influence upon the location of New England manufacturing towns. Lowell, Massachusetts, with its great cotton mills dating back to 1826, is an example of an industrial city whose beginnings center around the development of its potential water power sites. The cities of Lawrence and Holyoke have similar histories. Biddeford and Saco, in the state of Maine, saw the installation of sawmills operated by hydraulic power as early as 1750. The influence of these early water power developments persists even to the present day. As late as 1869, when the first census of power equipment in this country was made, nearly half of the power used in manufacturing was derived from water wheels and water turbines, and even at the present time, the direct use of water power accounts for 18% of the total power used in New England manufactures.

Although the steam engine and the internal combustion engine have relegated water power to third place in the

total output of mechanical and electrical energy, this resource is by no means an unimportant factor in power supply and is again increasing in importance as the years go by. The marvelous efficiency of the modern water turbine and the rapid strides in perfecting the art of electrical transmission have served to bring into the range of economic use hitherto inaccessible water power sites of large potentialities.

Simultaneously with the technical improvements in the production and transmission of power, the past two decades have witnessed an unprecedented increase in the consumption of energy, and especially of electrical energy. For example, in 1910 the output of central electric stations was about 9 billion kilowatt hours; by 1915 it had nearly doubled; and in 1927 it reached a total of 75 billion kilowatt hours, or nearly an eightfold increase in 18 years.

As a consequence of these comparatively recent developments, an intense interest in the possibilities of water power as a factor in the general power situation has been aroused. With this display of interest certain questions arise. Is it economical to develop water power in competition with steam power? Should water powers be under public control? Or shall they be publicly owned? Shall the states or the Federal Government control their development and regulation? This study deals with these and other questions.

THE IMPORTANCE OF POWER IN MODERN LIFE

The tremendous increase in power output leads us to an examination of the underlying causes. Why should more than 90% of the mineral output of the United States be represented by the energy minerals? Why has the output of power increased so much faster than the output of iron or copper, or other important raw materials? The answer is not far to seek. Power is the basis of our present-day industrial organization. Modern nations expend far more energy than the combined muscular ability of their populations and

beasts of burden. In fact, modern industrialism is possible, on its present large scale, only because man has learned to harness the forces of nature and to employ them in useful work.

The social response to this enormous use of mechanical power is a departure from the self-sufficient order of gaining a livelihood and a continued advance toward integration of production. The introduction of the power-driven machine and the specialization and division of labor have replaced the self-reliant workman of yesterday. This change, familiarly known as the industrial revolution, is still going on, and will continue to develop further in the future. The effect of such widespread use of power upon the everyday life of the individual, especially the urban dweller, is just as far reaching as is the change wrought upon his status as a worker. His welfare and continued comfort are linked closely with an uninterrupted supply of power. Together with food, clothing, and water, power may be considered as one of the important necessities of life. The food for his breakfast table is brought in by power-driven freight trains from the wheat fields of the West or from the fruit orchards of the South and West. The grain is prepared into a suitable form of food by power-driven machinery. Likewise, the home in which the individual lives is a product of cement, brick, lumber, glass—materials which consumed power in their manufacture. In his daily activity the urban dweller is continually dependent upon a supply of power. He is taken to his place of work in an electrically driven street car, where a power-driven machine is his helper throughout the day, or, in an office, he is carried up by an electrically operated elevator. In the home, the silent service of gas and electric power requires many tons of coal at the distant gas plant or power station. Far from being a luxury, or even a convenience, a supply of power is a vital necessity to the present-day conditions of life. To stop the supply of power would result in serious privations and even starvation for many people in all walks of life.

EXTENT OF AMERICA'S POWER RESOURCES

This country is indeed fortunate in having a great storehouse of energy resources. The largest source of power is, of course, coal. Of the world's coal supply, estimated at 8,000,000 million tons, we have approximately one-half. Our annual consumption is about 600,000,000 tons. In regard to petroleum the situation is not so fortunate. We produce and import over 900,000,000 barrels annually, of which 500,000,000 barrels are required to supply fuel for 25,000,000 automobiles, 60,000,000 barrels are needed for oil-burning ships, 50,000,000 barrels are used by our railroads, 130,000,000 barrels are needed in various industries, and about 60,000,000 barrels are consumed annually by our central stations producing gas and electricity.[1] Although the present reserve is still large, the exhaustion of the oil fields is a matter of only a few decades, and the problem of utilizing this natural resources in a more economical way is a very serious one.

The third important energy resource is hydraulic power. Although the amount of mechanical and electrical power obtained from water is less important than that from either coal or petroleum, this resource has the unique characteristic of being nonexpendable, which places it in a prominent position in a consideration of power supply. A power site, once harnessed, is practically permanent. Every horse-power-year of power generated by hydraulic power represents an annual saving of approximately 4 tons of coal. In this respect the immediate development of water power resources, wherever it can be done economically, represents a saving of coal reserves for future generations.

PUBLIC INTEREST IN WATER POWER UTILIZATION

The American public has long been interested in the development and use of water power resources. It has felt

[1] Louis C. Loewenthal, "Power Generation," *Journal of the Franklin Institute*, Vol. 201, No. 4, April, 1926, p. 432.

that this resource is, in a peculiar sense, public property and that the public interest in its development must be jealously safeguarded. Public interest is opposed to private development of water powers in such a way as to permit capitalization of unearned increment for which future power users might be asked to pay returns. Cheap power promises to be, in some future century, this country's largest asset in industrial rivalry among nations. Hence the people's interest in retaining control over hydraulic resources lies in the fact that hydroelectric power at the lowest possible cost consistent with a fair return on actually invested capital gives the promise of the greatest social progress.

It is true that this interest has often been accompanied by a grossly exaggerated idea of the extent of the water powers of this country and of the part that they will play in our future power requirements. The popular imagination has allowed itself to believe in many instances that hydraulic power can supply nearly all of our needs of power and light. A prominent manufacturer some time ago referred to coal mining as a dirty and disagreeable job, which no doubt it is, and suggested that we substitute hydroelectric energy for carboelectric energy to turn the wheels of industry. To what extent can his suggestion be carried out? Is this natural resource likely to become a competitor of coal? These and other questions are constantly being asked. The answer can be found only in a survey of the available resources and an analysis of the economic conditions that surround their development.

A study of the economic possibilities of water power utilization involves, first, an analysis of the costs of producing hydroelectrical energy in comparison with electrical energy derived from coal- or oil-driven engines for a given site, and, secondly, a study of the peculiar economic conditions which surround the utilization of hydraulic resources in the several water power areas of the United States and Canada. Water power, unlike coal, cannot be transported, except in the form of electrical current, and then not eco-

nomically for more than 200 or 300 miles with present technical development of transmission. Practical utilization requires, therefore, that hydroelectric energy be consumed reasonably near the point of production. Hence the value of water powers in a region depends, not only upon the cost of developing the site itself, but also upon the condition of the market and the extent of industrial development in the adjacent territory. For example, the development of a hydroelectric plant on one of the many feasible sites of the Nelson River, in Canada, could, no doubt, be accomplished at a low cost per unit installed horsepower, but the lack of a market in this far northern, sparsely settled country would make such an investment unprofitable, whereas the same expenditure of capital per horsepower on the Niagara River would prove highly profitable. In the discussion that follows, the general principles of water power economics will first receive attention, followed by a discussion of regional problems.

II

ELEMENTS OF THE WATER POWER PLANT

Elements of the water power plant. Water wheels. The modern turbine. The dam. The auxiliary equipment.

THE general elements which enter into a hydraulic plant are the water turbines, the dam and its appurtenances, and the electric generator for converting into electrical energy the mechanical power developed by the turbine. Although the water turbine was developed only in the last century, the harnessing of water power by means of water wheels dates back at least to the Christian era. The earliest water motors were "current wheels." These were large wheels with pad-

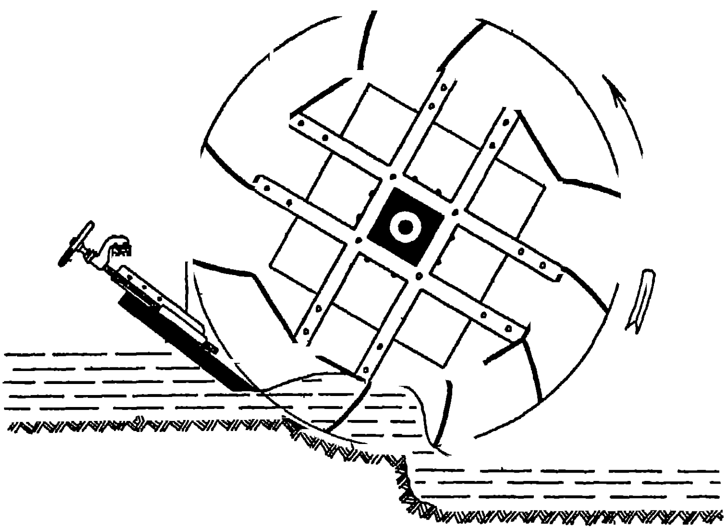


Figure 1. Undershot water wheel.

dles which dipped into the stream and were turned by the velocity of the current. The efficiency was very low, probably between 3% and 5%.

An improvement of the "current wheel" was the "undershot" wheel (Figure 1). In this case a greater efficiency was obtained by conducting the water through a flume whereby a greater velocity could be secured, and the wheel was made with small clearance at the bottom and sides so that practically the whole of the water was made available to drive the wheel. With this improvement the efficiency was raised to from 25% to 40%. A modification of the "undershot" wheel consisted in building the bottom of the flume with

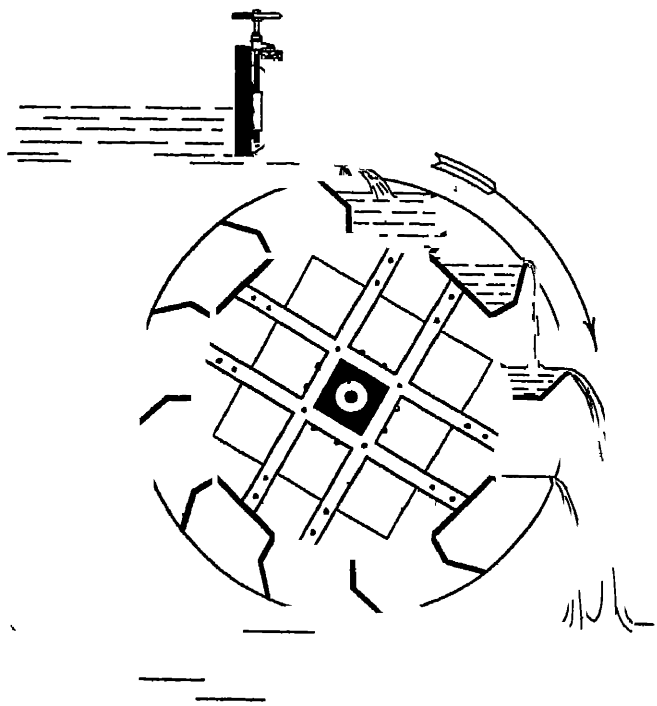


Figure 2: Overshot water wheel.

very small clearances to the center of the wheel. This was known as the "breast wheel" and had an efficiency of 50% or over. The "overshot" wheel came into use soon after the undershot wheel. It was built with buckets which were filled with water at the top of their travel. The weight of the water turned the wheel, and efficiencies exceeding 85% were often reached. See Figure 2.

THE MODERN TURBINE

The water wheels described above, while interesting as the pioneers in the harnessing of water power, have been rendered obsolete by the introduction of the turbine. From a modest beginning in 1844, when Boyden designed a 75-horsepower wheel for use at Lowell, Massachusetts,[1] the history of the turbine has been one of continued improvement, modification, and increase in size until, at the present time, 70,000-horsepower units are in use. The usual arrangement of the turbine and the position of the generator in the power house is shown in Figure 4. Turbines are also placed with the shaft in a horizontal position, but recent large installations seem to favor the position of the turbine and generator shaft in a vertical position, as seen in Figure 4, which shows the layout of the power house of the Queenston-Chippewa plant of the Hydro-Electric Power Commission of Ontario, with the penstock conducting the water from the forebay above.

THE DAM

The purpose of the dam is primarily to afford a head of water to operate the turbine, but its function in creating pondage or storage is often of great importance. The dam is likely to be the most important feature of a power development and, therefore, the item of greatest cost. More than any other part of the plant, it is exposed to the forces

[1] R. H. Fernald, and G. A. Orrok, *Engineering of Power Plants,* 1921, p. 541.

of nature, of water, and often ice pressure, which it must safely withstand at all times and under all conditions. The principal types of dams are masonry, earth, timber, and concrete.

THE AUXILIARY EQUIPMENT

The operation of a water power plant requires certain auxiliary equipment in addition to the power or storage dams and the turbine. This auxiliary equipment is required either

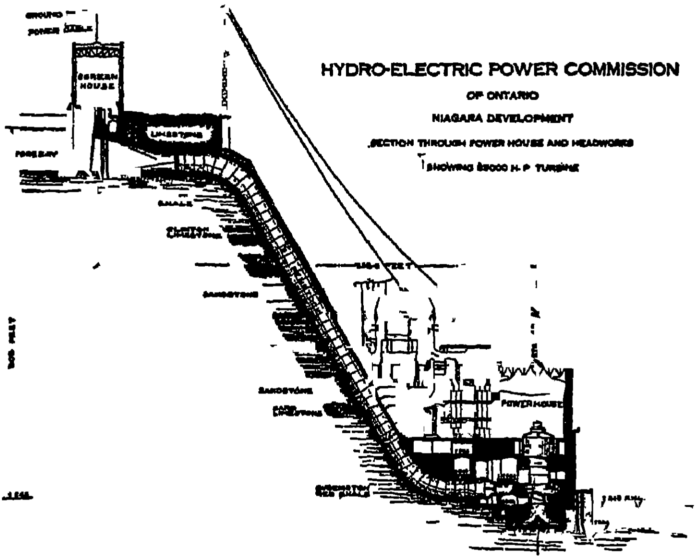


Figure 3: Power house and dam at the Queenston-Chippewa plant of the Ontario Hydro-Electric Power Commission

to control the flow of the water in the operation of the plant or to fulfill the requirements of state and Federal laws and regulations governing the use of streams. The principal elements required for the control of water are penstocks, forebay, gates, trash racks, and valve houses. In addition to these, laws of the state or the Federal governments

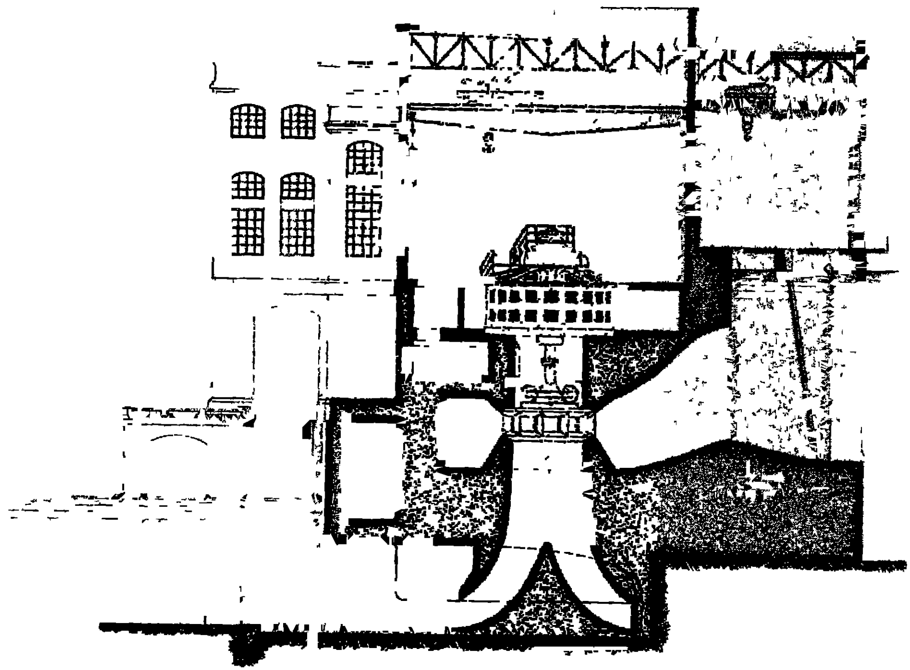


Figure 4 Section of power house showing turbine, generator, and water conduits leading to and away from turbine

usually specify fishways and log chutes. Where the power house is located at the foot of the hill, the water is conducted from the dam to the turbine by means of a short tube known as the penstock. In case the water is conducted through a canal or flume over a considerable distance from the source, the end of the canal leading up to the penstock is widened to accommodate a greater volume of water. This widened channel is known as the forebay. The accompanying illustrations will give the reader a clearer conception of the general design of a hydraulic plant.

III

PRINCIPLES OF WATER POWER ECONOMY

Early predominance of water power. The decline of water power. The revival of water power. Interconnected power systems. Water power, coal, and petroleum Water power and the stationary power equipment of the United States. The theoretical contribution of water power. Elements of cost in hydroelectric development Steam-electric *vs* hydroelectric power. Preliminary investigation expenses. Promotion and organization expenses. Cost of acquiring a site. Cost of constructing a plant. Hydrological conditions affecting the cost. Costs of transmissions and rights of way Costs of developmental period. Operating costs. Condition of the market to be served. Influence of the load factor. Development costs and public control

THE early importance of water power, which has been sketched in the previous chapter, lay in the fact that, for a time, it was the only source of mechanical power. Its only competitor was the muscular power of animals or of human beings, and, for the simple manufacturing establishments of this early era, water power was the most convenient. The practical effect was to establish a close relationship between power streams and factory locations. This is in direct contrast with modern industrial conditions, where raw materials, labor supply, transportation facilities, and markets exert a greater influence on the location of factories than the supply of power. The above condition existed until the arrival of steam.

THE DECLINE OF WATER POWER

Water power, supreme as a source of mechanical power for nearly two centuries, eventually capitulated to the steam engine and now occupies a relatively unimportant position in the mills and factories. Nevertheless, the steam-driven motor seems to have displaced the water wheel rather

slowly. Although coal was being mined in considerable quantities as early as 1830, the water motor still turned nearly half of the wheels of industry as late as 1869. From that time on the decline was rather rapid, so that in 1919 water power used directly in manufacturing fell to 6%. The waning importance of the water wheel as a source of direct mechanical power is shown in Table 1.

TABLE 1

GROWTH OF TOTAL HORSEPOWER USED IN MANUFACTURING, WATER POWER USED (DIRECTLY) IN MANUFACTURING, AND PERCENTAGE OF WATER POWER TO TOTAL*

Year	Total Horsepower	Water Power	Percentage of Water Power to Total Power
1869	2,346,142	1,130,431	48 1
1879	3,410,837	1,225,379	35 9
1889	5,938,635	1,225,045	21 1
1899	10,097,893	1,454,112	14 4
1904	13,487,707	1,647,880	12 2
1909	18,675,376	1,822,888	9 8
1914	22,437,072	1,826,443	8 1
1919	29,504,792	1,765,263	6 0

* Abstract of the *Census of Manufactures*, 1919, p. 460.

The causes of the decline are several. Obviously the most important of these is the introduction of the steam engine, but other factors contributed to hasten the relegation of water-driven motors. The economy of locating factories near raw materials or routes of transportation and of carrying power (in the form of coal) to the plant placed the steam engine in the favored position. The increasing size of machines used in manufacturing necessitated the installation of larger power units. For this the early water wheels were inadequate, and steam took their place. Finally, the decline of certain industries peculiarly adapted to the use of mechanical water power, such as gristmills and pulpwood manufactures, brought about the obsolescence of a portion of the water power equipment.

THE REVIVAL OF WATER POWER

If the early importance of water power as a source of mechanical energy was doomed to disappear, its place in the field of electrical power production is assuming an ever-increasing importance. At the present time, hydroelectric installations aggregate five times the installed capacity of the mechanical hydraulic plants, and, if projects now contemplated are finished, the total amount of harnessed water power will be doubled in the next few years. The rapid development in this new field can be explained on two grounds: first, the perfection of the water turbine and the marvelous developments in the art of producing and transmitting electrical energy, and, second, the rapid increase in recent years of the use of power and especially electrical power. The water turbine has been constantly increasing in size and efficiency, so that now 70,000-horsepower turbines with an efficiency of 88% are being installed, an achievement which makes possible the harnessing of the largest rivers and the installation of enormous plants. The perfection of the turbine was paralleled by another equally remarkable achievement, the high-tension transmission lines which carry the power to the distant market. From its beginning in 1892 to the present time progress has been rapid. In that year the San Antonio Light and Power Company built the Pomona plant in southern California. The energy was transmitted to San Bernardino, 28.75 miles away, at a pressure of 10,000 volts, the first long-distance high-voltage line in America. By contrast, Pit River plant No. 1 of the Pacific Gas and Electric Company, completed in 1922, thirty years after the Pomona plant, is 290 times the size of its historic predecessor, transmits energy seven times the distance at 220,000-volt pressure, and is operated by no larger a labor force. Improvements of this kind in the efficiency of electrical transmission (and there is good reason to believe that further economies in transmission will be effected) have brought within the reach of the power mar-

ket vast hydraulic resources hitherto inaccessible or too far removed to be developed profitably.

The second factor that explains the increasing importance of hydroelectric power is the recent rapid growth in power demand, and especially in the demand for power in the form of electrical energy. That this form of power is fast becoming important in the manufacturing industries, as well as for public utilities, is clearly illustrated in Table 2. Analysis of the primary horsepower used in the principal industries in the United States in 1924 shows that 13,359,096 horsepower, or about 40% of the total power used, is in the form of electrical energy.[1] Of greater significance, probably, is the rate at which this proportion has increased since 1900.

TABLE 2

PROPORTION OF ELECTRIC POWER TO TOTAL POWER USED IN MANUFACTURING, FOR SPECIFIED YEARS*

Year	Total Horsepower	Electric Power	Percentage
1869	2,346,142	..	.
1879	3,410,837	.	.
1889	5,938,635	..	
1899	10,097,893	182,562	1 8
1904	13,487,707	441,589	3 3
1909	18,675,376	1,749,031	9 4
1914	22,437,072	3,897,248	17 3
1919	29,504,792	9,347,556	31 2
1924†	33,143,753	13,359,096	40 4

* Abstract of the *Census of Manufactures*, 1919, p. 44.
† *Electrical World*, January 2, 1926.

The tardy development of the electric motor in industry is partly due to hesitation on the part of plant owners to scrap their existing steam plants. However, the obvious advantages of the electric motor eventually overcame this inertia, so that from 1909 to 1924 the rate of increase was very rapid. Electrical energy makes possible the application of smaller power units than with steam or internal com-

[1] *Electrical World*, Vol. 87, No. 1, January 2, 1926, p 44.

bustion engines, as, for example, an electrically driven vacuum cleaner. Of the total power used in manufacturing in the United States, the average size of the unit for each type of motor is given in Table 3.

TABLE 3

TOTAL POWER USED IN MANUFACTURING, BY TYPES OF POWER, AND THE AVERAGE POWER PER UNIT*

Type of Power	Number of Units	Total Power	Average Power per Unit in Horsepower
Steam engines......	116,183	13,839,832	119
Steam turbines	6,445	3,198,141	4,955
Internal combustion engines	33,407	1,259,400	38
Water turbines and generators	14,008	1,765,263	126
Electric motors.........	996,000	9,347,556	9 4

* Abstract of the *Census of Manufactures*, 1919, p 460.

Moreover, electric power can be transported to any part of a plant, or to a plant anywhere in the city or its vicinity, without much loss of energy. It adapts itself to units of any size, from a fraction of a horsepower to several hundred horsepower. Cleanliness, compactness, high speed, adaptability to a variable load, are other factors which contribute to its desirableness as a form of power. Hence, one finds the tendency to concentrate steam, and to some extent gas, into larger power units for the generation of electrical current, in which form the energy is distributed over transmission lines to the points needed.

Finally, the growth of central station output and its relation to hydroelectric plant development deserve consideration. That the output of the central station is no longer confined to domestic users and city utilities but is rapidly finding favor with manufacturers is shown by the rapid growth of the load. The accompanying graph, Figure 5, shows in a striking way how rapid this growth has been.

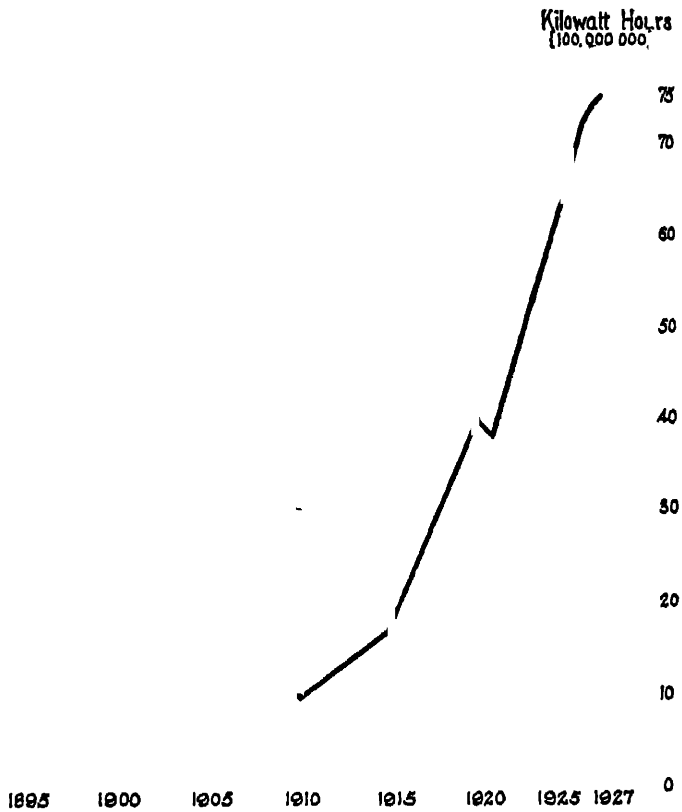


Figure 5: Energy output of central stations of the United States, 1895-1926.

INTERCONNECTED POWER SYSTEMS

Not only have the types of customers of the central station increased in number, but also, the area served by a single system has increased in size, with the result that individual units have been grouped together into one interconnected system. This concentration of power production into central station systems deriving their power from several units, probably both steam and hydro, serves to enhance the

value of water power sites. No longer is it necessary to build a factory at a given site to use the available power, or to rely upon a nearby community to absorb the surplus energy of such a development. Instead, the current developed at a given site can be transmitted to a central station and distributed through it in a diversified market for the industrial and domestic consumers in several adjacent towns or communities. The logical outlet for hydroelectric energy, especially where developed at sites located away from industrial centers, is through interconnection with such a central station system.

While an interconnection of this sort is an important factor in accomplishing a more effective employment of the power equipment of a locality, its supposed economies have been greatly overestimated by the public at large. The terms "superpower" came into use only after the art of electrical transmission had reached a point where large blocks of power were being transported over great distances at high voltages. Essentially, it refers to a system of power production and utilization whereby the energy is produced at a central station and then carried over wires to the consuming point in quantities large or small, varying from the amount needed to light a home to quantities large enough to turn the electric motors of a factory. Hence, the first steam-electric plant was, in fact, the beginning of a superpower system. Following closely upon the remarkable expansion of the use of electrical power in the past two decades came the need for larger central stations carrying larger quantities of electricity over greater distances. This naturally led to the next step of tying together two or more power plants into one system for the purpose of supplying power to a larger locality. Certain economies were effected by such an arrangement. Overhead was reduced by reason of a larger plant being operated by a relatively smaller labor force, coal was more effectively burned, and the load factor could probably be increased with consequent reduction in the cost per kilowatt hour. The constant improve-

ment in the art of transmission brought into use water power resources that were remote from the consuming centers, and hitherto unavailable. Wherever these hydroelectric plants were operated in connection with a steam-electric system, new problems of economical station management appeared. Eventually it became clear that certain economies could be effected by the interconnection of power systems over a wide area, covering, in many instances, several states. The wide publicity which accompanied these interconnections under the magic term "superpower" created in the mind of the public an expectation of cheap power entirely unwarranted by the extent of the economies brought about. Coupled with this misconception was that of a grossly exaggerated estimate of the water power possibilities in the United States, a misconception which visioned the abandonment of coal mines and the use of water-generated electrical energy to satisfy all the power wants of man. Although these extreme expectations are absurd, there are, nevertheless, substantial economies that can be effected by interconnection, and the more important ones are here stated:

1. Owing to diversity in peaks, interconnection may increase materially the load factor which may be carried on otherwise separate systems.

2. Interconnection enables a generating system to operate with less equipment in reserve.

3. Interconnection among hydroelectric plants makes possible the fullest utilization of water powers and existing watersheds. The diversity frequently existing in the high-water period of neighboring streams is utilized advantageously by moving surplus power from one station to another.

4. In the case of interconnection between existing steam-electric plants the most efficient stations may be operated at a maximum load factor, while the less efficient plants need be called into service only when required.

5. Where hydroelectric plants are connected with steam-electric systems, greater economies may be effected in the

operation of the steam plant. "Water-power developments having ample storage reservoirs are peculiarly adapted to operation under low-load factors, whereas steam plants are most economical when carrying full loads continuously. As an explanation of this, it is known that when steam turbines are operated during peak-load periods only, heavy standby losses are incurred during the remainder of the day, as boilers of corresponding capacity must be banked and held ready for service. On the other hand, hydroelectric units, when idle, are free from practically all standby charges except fixed charges."[2]

6. Interconnection makes possible a saving of capital invested. "A recently completed interconnection among the Hartford, Springfield (Massachusetts), and Turner Falls companies, with an outlay of about $700,000, has saved $3,000,000 investment in steam plant capacity."[3]

WATER POWER, COAL, AND PETROLEUM

The mere presence of water power sites in a locality, or the fact that a region or a country is richly endowed with these resources, does not necessarily imply that they will be utilized. Hydroelectric energy, like any other commodity, must enter a competitive market, and in this case the competitor is carboelectric energy generated by coal or petroleum.

The chief competitor is, of course, coal. The total reserves in this country have been estimated by the United States Geological Survey at nearly four million million tons, a quantity sufficient for thousand of years to come. The geographical distribution of the deposits is such that only in the Pacific states does water power possess any decided advantage of location. The cost of steam-generated power is more likely to decrease than to increase in the near

[2] Chas B Hawley, "Discussion of the 'Economics of Hydroelectric Development'," *Proceedings of the American Society of Civil Engineers*, August, 1924.

[3] *Ibid.*

future, inasmuch as the ever-increasing efficiency in fuel utilization will very likely more than offset any possible increases in coal costs arising from the exhaustion of the more easily mined seams. In fact, the present trend is toward a reduction in cost of steam-generated energy.[4] The technical improvements in power transmission which have been noted as aiding the utilization of water power sites is equally advantageous to the utilization of coal fields. Finally, the higher-grade coal deposits are near the large power-consuming centers, whereas nearly three-quarters of the potential water power is in the sparsely populated western states. The slow development of water power is, in a large measure, accounted for by reason of the cheapness of its chief competitor, coal.

The competition of petroleum with water power as a source of energy is, except in a few instances, unimportant. The principal users of petroleum products, the automobile, the railway engine, and the ocean liner, are not adapted to the use of electrical energy. Only in California, where fuel oil and water power are abundant, but where coal is lacking, does petroleum enter into competition with hydro plants in the generation of central station power for street railway, industrial, and domestic lighting loads. In 1923, fuel oil supplied about 70% of the power requirements of the state,

[4] "There was a marked improvement in efficiency in the utilization of fuel in the production of electricity by these power plants in 1926. Although the increase in output by the use of fuels was 9%, the increase in fuel consumption was only about 2%. The average rate of consumption of coal in 1926 was 1.95 pounds per kilowatt hour, showing a gain in efficiency of about 8% during the year.

"To have produced the electricity generated by the use of all fuels in 1926 by the use of coal alone would have required 46,400,000 tons at the average rate of coal consumption in 1926, or 76,000,000 tons at the average rate in 1919—a difference of nearly 30,000,000 tons This figure indicates the immense saving in coal brought since 1919. At the present time at least one plant is using only about 0 85 pound of coal to produce a kilowatt hour of electricity. If all the electricity produced by the electric public utilities in 1926 by the use of fuels had been produced by the consumption of 0 85 pound of coal per kilowatt hour, the conservation of coal would have amounted to 26,000,000 tons, which is equivalent to about $100,000,000" Quoted from Mimeographed release No. 12876, February 16, 1927, of the U. S Geological Survey.

and it is logical to expect that a decline of California Oil production will bring about a substitution of hydroelectric power for oil-fired generating stations. However, the continued high productivity of the California oil fields since 1923, when their decline was predicted, together with the discovery of new reservoirs of oil in the deeper sands of some of the old fields, may indicate that oil will hold a leading position in the power needs of this state for many years to come.

WATER POWER AND THE STATIONARY POWER EQUIPMENT OF THE UNITED STATES

The utilization of water power is confined almost entirely to the production of electrical energy, and, as such, it can be marketed only through the central station to manufacturing customers or to the public utilities. The importance of the water power resources of the country, then, must be measured by their comparison with the present and future demand for electrical energy. The total primary horsepower in industrial plants in 1924 was in excess of 33,000,000 horsepower, of which 22,000,000 horsepower represented electrical motors deriving their power either from central stations or from a private plant. The energy consumed in 1924 was 31 billion kilowatt hours.[5] The installed capacity of central stations in 1927 is estimated at 37,900,000 horsepower and the energy output was 75,100,000,000 kilowatt hours.[6] The total installed electrical power in the country is, therefore, about 60,000,000 horsepower. At the present time water contributes about 10,000,000 horsepower to the total stationary power equipment. The rapid growth of the use of electrical energy in the manufacturing industries has already been noted in a previous table. The increase in the output of electrical energy from central stations is even more pronounced, as shown in Table 4.

[5] *Electrical World*, Vol. 87, No. 1, January 2, 1926, pp 44, 45.
[6] *Ibid.*, Vol. 89, No. 1, January 5, 1928, p 19.

TABLE 4

CENTRAL STATION OUTPUT*

Year	K.w hr Output (000 omitted)	Year	K w.hr. Output (000 omitted)
1913	13,000,000	1921	36,970,697
1914	14,400,000	1922	43,559,677
1915	16,175,000	1923	51,132,883
1916	21,230,000	1924	54,413,403
1917	25,438,000	1925	61,159,000†
1918	29,200,000	1926	69,158,000†
1919	34,900,000	1927	75,116,000†
1920	39,518,903		

* *Electrical World*, January 2, 1926, p 18.
† *Ibid.*, January 7, 1928, p 32.

THE THEORETICAL CONTRIBUTION OF WATER POWER

It has been noted above that the fields for the marketing of hydroelectric energy are among the users of electrical energy in the manufacturing industries and among the customers of central stations. The potential water power of the United States, as estimated by the United States Geological Survey, approximates 50 or 60 million horsepower, slightly more than the present installed electrical horsepower. From these estimates, it would appear that water power could displace stationary steam power. However, a further examination of the situation reveals several conditions which severely limit the potential water power that can actually be so employed. The major portion of these resources, about 70%, is located in the Mountain and Pacific states, in a region where the local market can at present absorb only a small percentage of the available power. Moreover, the cost of carrying this power over a wide expanse of territory to a market is, under present conditions, prohibitive. In the second place, many water power sites, although they may be located near a market, can be developed only at a cost per unit of installed horsepower exceeding that of a steam plant. A study of the applications before the Federal Power Commission indicates that the economical

maximum of development may not exceed 25,000,000 horsepower for some time to come.[7]

ELEMENTS OF COST IN HYDROELECTRIC DEVELOPMENT

"Cheap water power" is a term which occurs again and again in the daily press, in public discussions, and in the popular magazines. Is water power cheap in comparison with steam or gas? Does the fact that the water flowing over the cliff is nonexpendable make it a cheaper source of power than that derived from a fuel-using engine? If the element of fuel cost was the only one to be considered when comparing water power with steam, then indeed the advantage would be with water power. But there are a host of other costs that enter into power production. What these costs are in the case of hydroelectric development will be analyzed.

Flowing water represents the energy of the sun's rays in raising water by evaporation from sea level into the atmosphere, later dropping it upon the land surface and allowing it to run downhill to the sea. The potential energy possessed by the water in the mountain streams, or by the snow on the mountain tops, becomes kinetic energy when it drops over a cliff, or flows down the gradient of a stream bed. The energy contained in this falling water, unless uti-

[7] The approval of the Federal Power Act in 1920 was followed by a flood of applications for permits and licenses. The applications in active status at the end of each fiscal year, together with the percentage of increase, is as follows:

Year	Net Installed Horsepower	Percentage of Increase Over Previous Year
1921	15,024,000	
1922	19,995,000	33
1923	21,415,000	7
1924	21,695,000	1
1925	24,119,000	11
1926	24,755,000	3
1927	24,981,000	1

The sharp decline in the rate of increase after the first year may be an indication that, for the present, nearly all the sites that can be developed at a profit have been covered by applications.—Data obtained from *Annual Reports* of Federal Power Commission.

lized, is gone forever, just as an idle day takes with it the earning power of the laborer for that day. Neither can be stored up for the future. And, because the energy of a waterfall is allowed to go unutilized, many people, even some economists and engineers, have held the idea that this energy is going to waste. One of the arguments most frequently advanced is that the water powers, if harnessed, would save many thousands of tons of coal. This is true, but before accepting the statement that nonuse constitutes an economic waste, it is pertinent to inquire into the meaning of the word "waste" used in this connection.

The object of economic activity is to satisfy the many and varied wants of man. To accomplish this end, raw materials, power, labor, and capital are mobilized for the production of goods in the form, in the place, and at the time wanted by the consumer. Obviously, the most economical way of bringing about this result is to use that combination of factors (raw materials, labor, capital, and power) which will most effectively supply the want. When, therefore, it is possible to choose between two sources of power, coal or water, that one will be selected which can furnish the power more cheaply. In this connection it should be stated clearly that power derived from falling water is not necessarily cheap. Although the ledge or cliff over which the water falls or the steep gradient in the canyon through which the water courses may be the work of nature, unaided by man, yet the energy present in this falling water is impotent and useless until tamed and harnessed by man. For this harnessing, man-made structures are required, involving the use of capital and the labor of men which must be paid for in interest and wages out of the earnings of the plant before profits can begin. The widespread idea that water power is cheap power is due, also, to a misconception on the part of the public as to what items enter into the cost of power. In the case of hydroelectric energy the production of electrical power at the power house is only one of the items to be considered. Transmission, if the market be distant, and

distribution may make up more than 50% of the total cost to the ultimate consumer.

STEAM-ELECTRIC *VS.* HYDROELECTRIC POWER

The production of electrical energy by steam and water power is accomplished under such varied conditions that no general statement can be made concerning the relative cost of one compared with the other. The cost of steam-electric power varies with the size of the plant, type of plant, distance from fuel, load factor, and so forth. The cost of hydroelectric power varies with each site. Which will be cheaper for a given locality cannot be determined except by a study of the local conditions.

It should be pointed out in this connection that the growth of the power industry has not been spontaneous. A steam-electric plant can be installed to meet the demand that exists, and, as the power demand grows, a unit or two can be added. With hydroelectric plants the basic expenditures for dams, canals, and transmission lines are so great, and the time required for construction is frequently so long, that the demand must be foreseen a long time in advance and the installation made for a much greater capacity than the existing market demand. In this respect the hazards and costs of the hydroelectric plant are greater than in the case of steam. There are, however, certain costs which apply to both types of developments and which, therefore, may be compared.

The cost of producing electrical energy is made up of "original investment" and "operating costs." These may be further subdivided as follows:

1. Original Investment
   a) Preliminary investigation expenses
   b) Promotion and organization expenses, including plans, specifications, surveys, estimates, and legal expenses
   c) Land and water rights, including construction of roads and highways
   d) Power plant and structures, including reservoirs,

auxiliary steam plants, rights of way, transmission lines
   e) Cost of developmental period
2. Operating Costs
   a) Interest, depreciation, and taxes and insurance
   b) Production
   c) Transmission
   d) Distribution
   e) Administration

With the above enumeration of the factors of cost in the construction and operation of a hydroelectric plant, it will be desirable to analyze these factors which go to make up the cost of developing "free" water power.

PRELIMINARY INVESTIGATION EXPENSES

The Federal Power Commission is required, under the provisions of the act, to obtain estimates on the cost of any project and other data it may deem necessary for its information before issuing a license to an applicant. In order to obtain this information for the Commission the applicant must conduct preliminary geological and hydrological surveys, make borings and tests at the proposed dam site, investigate the legal status of the land and waters required for the proposed plant, prepare maps, plans, and specifications, submit estimates of cost, together with a plan for financing the project. In case of a large project this cost is no inconsiderable item. For example, the application of J. B. Girand, on the Colorado River, involving a project of 200,000 horsepower, necessitated the expenditure of over $100,000 in obtaining the data necessary for the application for a license.[8]

PROMOTION AND ORGANIZATION EXPENSES

After a license has been granted and before actual construction can begin, there is an additional expense for or-

[8] *Second Annual Report of the Federal Power Commission*, 1922, p. 177

ganization and incorporation, together with the costs of promoting and financing the project. Detailed surveys must be made, including investigation of site, location of roads, flowage lands, canals, and transmission lines. Plans, specifications, and contracts must be drawn up, and detailed estimates of cost of plant and equipment must be made. In this respect the preliminary cost of a hydroelectric plant far exceeds that of a steam-electric plant.

COST OF ACQUIRING A SITE

Securing a site for a hydroelectric installation is not complete with the acquisition of the land for the power house and the dam ends. Flowage rights and rights of way are also needed. Where low-head plants, constructed on rivers which flow through populous farming districts, are built, considerable pondage or storage is necessary to equalize flow or take care of load factors. Frequently it is necessary to relocate roads and highways—an added cost. The acquisition of flowage lands and rights of way may be difficult and expensive. In sparsely settled mountainous districts this item may be insignificant. For development for private use no condemnation proceedings are possible in most states, and sites, pondage area, and rights of way are sometimes held for exorbitant prices. Another probable expense is the excess flowage land needed for unusually high water periods.

COST OF CONSTRUCTING A PLANT

The cost of construction of a dam and power house for a hydroelectric plant is usually greater than the corresponding cost of a power house and equipment of a steam-electric plant.

The length of the dam, the nature of the foundation, the thickness of the dam, the accessories, such as fishways and navigation locks, are determined by the topography and rock structure at the dam site, the use of the stream for navigation, the nature of the stream flow, and so on.

Frequently it is necessary to dig to a considerable depth below the surface to reach bedrock suitable for making a water-tight dam. A broad, shallow river will require a long dam. If a plant is located in a mountainous district, as is frequently the case in the western states, its cost is not measured solely by the sacks of cement in the dam, and the pounds of steel in the equipment. Camps must be established, roads or railways built, construction equipment installed, foundations excavated and drained, reservoirs cleared, debris removed, and general overhead organization maintained. Few of these items are visible when the project is in operation, yet all have entered into and materially affected the cost.

HYDROLOGICAL CONDITIONS AFFECTING THE COST

The ideal stream for hydroelectric development is one of uniform flow, without silt, supplied preferably by a natural reservoir. Probably the nearest approach to this ideal is the Niagara River between Lake Erie and Lake Ontario, or the Nelson River, in Canada. Unfortunately, however, such conditions are rare, and most streams are subject to great variations in flow. These variations may be both yearly and seasonal, although the latter present the greatest number of problems to the engineer. Usually there are one or two seasons of high water and of low water during each year. High water occurs most frequently in the spring or fall, and low water during the late summer and during winter, when freezing locks up the supply of water. On the other hand, the market conditions usually require a more or less constant flow of power throughout the year. The annual load will vary somewhat with the season, and ordinarily does not correlate with the fluctuations in stream flow. These conditions of stream flow can be met in several ways, and, again, the nature of the stream, together with the local market conditions, must be taken into account in designing a plant of maximum economy. The various plans are:

1. *Development of the stream only to minimum flow.* Except for streams with a moderate fluctuation in flow this plan would be uneconomic. To illustrate this, the flow characteristics of three California streams are selected. These records are as follows:

River	Monthly Maximum Flow (*feet per second*)	Monthly Minimum Flow (*feet per second*)
Pit River	17,500	2,450
Feather River..	39,900	969
San Joaquin River	15,900	2 08

The cost of a structure needed to dam these rivers, together with the additional equipment that would have to be installed to take care of flood periods, would be excessive for the power that could possibly be obtained at low flow.

2. *Development of the site to use the maximum flow, and selling of all the power developable for part of the year only as secondary power at low rates to customers who could use power intermittently.* While this may be theoretically feasible, it is doubtful if industries requiring this periodic service could usually locate near the power plant. Power supply is not the only consideration in locating an industry, and any advantage of cheap secondary power might be offset by corresponding disadvantages.

3. *Establishment of steam auxiliaries.* By this method much secondary power can be converted into primary power. While this adds considerably to the capital cost and fixed annual charges, yet it may increase the value of the power so as to be profitable. A study of market conditions and possible prices must be made for each case.

4. *Construction of reservoirs to regulate flow.* This has the same effect as the construction of an auxiliary plant, in that it increases the amount of primary power. In this case, also, it is necessary to determine if the additional expense of storage will sufficiently increase the value of the power to make this profitable.

5. *Interconnection of hydroelectric plants with plants on other drainage basins, or with steam plants.* By widening the market area served by such an interconnected system, the load factor will probably be increased, which makes possible a more economical production of power through reduction in the size of the plant.

6. *Combinations of plans 3, 4, and 5.* The study of stream flow is vitally important as a preliminary step in designing a hydroelectric plant, and all the available information obtainable should be analyzed. It is necessary so to design the dam and flood gates as to take care of abnormally high floods. "Occasional floods may occur that greatly exceed those recorded, even in long-time records of maximum stream flow. A flood of about 133,000 cubic feet per second washed around the end of this dam (Oklahoma City Water Works) during October, 1923. The dam and flood control works . . . were designed to pass about 18,000 cubic feet per second. This was much in excess of the recorded flow, the records being very limited. A study of the hydrology of the stream leads to the conclusion that no flood equal to that of October, 1923, has occurred in 50 years, but that even a greater flood must be expected."[6] The design of dams to provide most economically for occasional floods needs the careful attention of the engineer.

The investment in a dam and its appurtenances is usually so large that the utmost care must be used to see that ample foundations are secured, flood control is provided for, strength and stability against debris and ice pressure is obtained, overflow around the ends is prevented, downstream erosion guarded against, and all other contingencies provided for. Failure to provide for any of these conditions may result in expensive delays or breakdowns during the construction period.

[6] D. W. Mead, "Economics of Hydro-Electric Development," *Proceedings of the American Society of Civil Engineers*, Vol. 50, No. 4, p 429. The above classification of methods of development is adapted in part from Professor Mead's article.

COSTS OF TRANSMISSIONS AND RIGHTS OF WAY

The factor of transmission is one which also deserves careful consideration. Although occasionally a water power site is near the market to be served, in a large majority of cases the site is at a remote point, and the energy developed must be carried a long distance before it has a sale value. Where the steam-electric plants compete with hydroelectric plants for a given market, the cost of building and maintaining a transmission line must be compared with the cost of transporting coal from the mine to the steam station. In regions where coal does not compete, and this is principally in the western states, the cost of transmission must be analyzed as part of the cost of original investment.

In Tables 5 and 6 are given the estimated cost of steel tower transmission lines per mile for different lengths, capacities, and voltages, as well as the cost of river crossings. A load factor of 40% to 50% has been assumed in preparing these tables. Both tables were prepared for conditions in Maine and may be fairly representative for similar regions. The mountainous topography of the western states will require an upward revision of these figures.

TABLE 5

ESTIMATED COST OF TRANSMISSION LINES*

Distance (*miles*)	Capacity of Line (*k.w*)	Line Voltage	Number of Tower Lines	Number of Wires per Tower	Total Cost per Mile
25	5,000	66,000	1	6	$ 3,500
25	10,000	66,000	1	6	5,000
25	20,000	66,000	1	6	7,000
50	10,000	66,000	1	6	5,000
50	25,000	66,000	2	6	10,000
50	50,000	100,000	2	6	14,000
75	50,000	100,000	2	6	14,000
75	100,000	150,000	2	6	20,000
100	100,000	150,000	2	6	20,000

* State of Maine, Public Utilities Commission, *Special Water Power Investigation*, 1918, pp 392, 393

TABLE 6

COST OF RIVER CROSSINGS

Distance (*miles*)	Capacity of Line (*k w*)	Line Voltage	Number of Tower Lines	Number of Wires per Tower	Total Cost per Mile
500	20,000	66,000	1	6	$ 2,000
1,000	50,000	100,000	2	6	16,000
2,000	50,000	100,000	2	6	70,000

COSTS OF DEVELOPMENTAL PERIOD

The period of time that elapses between the beginning of construction work and the full operation of a hydroelectric plant is sometimes of considerable duration, usually much longer than in the case of a steam plant. The reason lies in the peculiarities of hydroelectric installations. The initial cost for plant and permanent fixtures is usually very high, much higher than for a corresponding steam plant. Moreover, the time required for construction is longer. During all this period of nonproductiveness the interest on the bonds must be paid, and the deferred dividends on the preferred stock are accumulating. After construction is complete and the plant is ready for service, an additional delay occurs while the operation of the machinery is being tested, faults corrected, and weaknesses remedied. A second condition that frequently accompanies hydroelectric development is that the market demand may not be sufficient to absorb immediately all the power output of the plant operating at full capacity. Hence, there is an accumulation of overhead charges on the entire plant which must be paid for out of the earnings of a small part of the plant capacity. Moreover, there is considerable risk in a plant which ultimately depends for its earnings on a growing market. The rate of growth of the community may have been overestimated, industrial depression may cause stagnation over a period of years, or other causes may intervene to depress the rate of

growth. Under these conditions it may be several years before a plant can pay dividends to stockholders.

It is evident, therefore, that the success of a contemplated development depends not only on the original cost of installation, but also on the growth and development of the power market.[10]

OPERATING COSTS

As stated previously, operating costs include (*a*) interest, taxes, and so forth, (*b*) production, (*c*) transmission, (*d*) distribution, and (*e*) administration. Only in the first three of these items will there be substantial differences from the costs of steam-electric plants. Because of the greater investment in a hydroelectric plant, the first item of cost is likely to be higher than the corresponding cost of a steam-electric plant. Under production we may safely assume a lower cost, since the item of fuel is removed, and the operating force required is smaller.

The cost of transmission usually is considerable, by reason of the fact that hydroelectric plants are very often far from the market. A corresponding cost in steam plants does not exist, as the latter are usually built in the center of the market and there is no intervening transmission between the generator and the distributing switchboard. Transmission costs are made up of two items, (*a*) losses of current in transmission, and (*b*) annual operating cost of transmission lines. The latter is calculated at 25% of the original investment and is made up of the items shown in Table 7.

In Table 8 is given the total cost, cost per kilowatt transmitted, and the annual cost per kilowatt hour for the different lines.

Table 8 shows that power transmission at a cost of about 0.10 cent per kilowatt hour or less is obtainable for short distances, also that power to be transmitted economically over long distances must be in large quantities.

[10] D. W Mead, "Economics of Water Power," *Transactions of the American Society of Civil Engineers*, Vol. 88, 1925, p. 178.

TABLE 7

ANNUAL OPERATING COST OF TRANSMISSION LINES*

(Percentage of capital invested)

Interest	7%
Depreciation	6
Operation, maintenance, and taxes	12
Total	25%

Where the distance to be traversed is great and the nature of the country is such as to offer many obstacles to construction, the capital costs of transmission may be greater than costs of production. A careful study by the engineering

TABLE 8

ESTIMATED COST OF POWER TRANSMISSION*

Length of Line (*miles*)	Capacity of Line (*k w.*)	Total Capital Cost of Line	Capital Cost per k.w. transmitted (50% L. F. and 5% losses)	Cost per k.w. hr (with annual cost 25% of first cost)
25	5,000	$ 87,000	$37	0 10
25	10,000	125,000	26	0 08
25	20,000	175,000	18	0 05
50	10,000	250,000	53	0 15
50	25,000	500,000	42	0 12
50	50,000	700,000	29	0.08
75	50,000	1,050,000	44	0 13
75	100,000	1,500,000	32	0 09
100	100,000	2,000,000	42	0 12

* State of Maine, Public Utilities Commission, *op. cit*, p. 393

staff of the Federal Power Commission of a proposed dam on the Colorado River resulted in the following estimates:[11]

Cost of dam, power house, generating equipment and step-up transformers	$128 per h.p.
Cost of transmission, including six substations	132 per h.p.
Total	$260 per h.p.

[11] O. C. Merrill, *Some Popular Fallacies Concerning Power Development* Paper prepared for Convention of Southern Appalachian Water Power Conference, Asheville, North Carolina, June 27, 1923.

In the great project for harnessing the Rhone conceived in 1917 the cost of carrying the power 400 kilometers (approximately 250 miles) to feed the great plant of Genissiat at Paris proved nearly as great as the cost of operation of the plant itself.[12]

The cost of distribution and administration is usually independent of the source of power, but a brief discussion of its importance may well be introduced here to correct certain misconceptions which are prevalent. Frequently there is a failure to distinguish between operating costs computed at the generator switchboard and such costs computed at the consumers' meters.

Studies made by the California Railroad Commission in a rate case before that body are illuminating as indicating the variation in cost of energy from the hydroelectric plant to the retail consumer. The figures are actual average costs to one of the large California electric utilities, such costs including operating expenses, depreciation, and return on the investment for each part of the system considered. The average energy cost at the generator switchboard is 4.25 mills, less than one-half cent per kilowatt hour. To guarantee continuous service and to furnish part of the energy supply in periods of low water, it is necessary to add operation, depreciation, and interest on steam reserve plants, thus increasing the cost to 6.28 mills. Transmission losses and costs, taxes and general expenses bring the average cost of power at the substation up to one cent per kilowatt hour. The distribution costs from the substation to the agricultural or industrial consumer having an installation of about 20 horsepower practically doubles the cost, making his charge 2 cents per kilowatt hour. When we consider the domestic lighting consumer, however, we find that his cost is primarily in the local distribution; that is, in interest, depreciation and maintenance on the distribution system and meters, in the expenses of handling consumers' accounts, and in taxes and other general expense items chargeable to this class of service. The California studies show that while the cost at generator switchboards is only 4.25 mills, at the substation only one cent, and when delivered to the general power consumer slightly less than 2 cents, the cost of delivery to the ordinary residence consumer is 7.4 cents; and that of this aggre-

[12] Raoul Blanchard, "Geographical Conditions of Water Power Development," *Geographical Review*, January, 1924, p 92.

gate cost, less than 6% is chargeable to hydro generation, while 88% occurs between the substation and the consumers' fixtures. This situation cannot be too often emphasized, for nothing but a clear exposition of the facts from a wholly disinterested source will convince the average consumer of electric energy that the wide difference between costs at the generator switchboard and the price which he pays, represents anything but profits to the utility, and extortionate profits at that.[18]

CONDITION OF THE MARKET TO BE SERVED

After the costs incident to construction, development, and operation have been considered, it is necessary, if the installation is to be a financial success, to survey carefully the conditions under which the power is to be marketed. When the development is undertaken by a concern already in the field and operating a plant to which the new hydroelectric plant is merely an addition, the problem is fairly simple. The market price of power is known, the market capacity of the community is fairly well understood, and it is definitely known beforehand what income may be expected from a plant of known capacity. When, however, a hydroelectric plant is built to serve a community already being supplied, in part at least, by a rival concern, the problem becomes more difficult. Under these conditions the selling price of power must be less than that of the established concern, otherwise customers will continue to buy from the latter or, in the case of isolated power plants, they will continue to manufacture their own energy. If the rate at which the users of electric current can be induced to become customers of the hydroelectric plant must be so low as to equal the actual cost of power, there will be no incentive for the construction of the plant. Where the market is supplied by a central station, a combination between the hydroelectric and the steam-electric plant is frequently the only profitable arrangement. When an altogether new market is to be developed, a careful survey of the potential

[18] O. C. Merrill, *op. cit.*

market is necessary. A census of possible power users should first be made. The maximum possible price at which hydroelectric power can be sold will be governed by the cost of generating such power by the ordinary fuel means. The minimum price is, of course, the actual cost of power development. If a market large enough to absorb all of the available hydroelectric energy can be obtained with the price somewhere between the limits stated above, the development may go on.

INFLUENCE OF THE LOAD FACTOR

A factor bearing upon the cost of electric current apart from any competitive condition is the load factor. The cost of a kilowatt hour of electric current is, theoretically, the cost of operating the plant plus fixed charges divided by the number of kilowatt hours produced. If the plant is operating at full capacity 24 hours of the day, obviously the cost per kilowatt hour is far less than that of a plant of similar size that is using only a fraction of its capacity for all but a small part of the day. There is, in actual practice, a wide variation in load factor among the various types of customers; hence the character of the load bears a very direct relationship to the cost of power.

DEVELOPMENT COSTS AND PUBLIC CONTROL

The rigid control exercised by public agencies, state and Federal, over the financial policies, rates charged, and services rendered by the hydroelectric power corporations is such as to limit the income to a reasonable return on actual investments. If the powers invested in the public agencies, particularly the Federal Power Commission, are effectively used, they will serve to prevent the appropriation of unearned increments on valuable water power sites by speculators. Moreover, investments in sites which show no promise of being profitable can be prevented as well as

attempted developments of feasible sites by parties who cannot adequately finance an undertaking of this kind. The practical effect of public regulation, as developed at the present time, in addition to safeguarding the interests of the consumers, is to prevent the waste of capital in unprofitable ventures, or in projects undertaken by parties not properly qualified to complete the work. Inasmuch as the economic importance of social control is likely to become increasingly significant in the future, an analysis of the legal basis of public regulation will be presented in a later chapter in order to define more clearly the present status and extent of social control.

IMPORTANT WATER POWER REGIONS OF NORTH AMERICA

INTRODUCTORY STATEMENT

ALTHOUGH water power resources are located in every state in the Union and in all the provinces of Canada, this distribution is exceedingly unequal, ranging from a few thousand horsepower in some of the Gulf Coast and Prairie states to enormous resources running into millions of horsepower in such states as Washington, California, and New York. The physical and economic conditions which surround the development and utilization of water powers in different parts of the country, especially where the large concentrations of power occur, differ so markedly that each presents economic problems of development peculiar to itself. The general analysis of the economics of water power development, therefore, must be supplemented by further detailed treatment for each section in which water powers are abundant.

For this purpose the country has been divided into five major water power sections as follows:

1. The St. Lawrence Valley, which includes the entire drainage basin below Lake Erie, also including the large tributaries of the St. Lawrence River in the provinces of Ontario and Quebec.
2. The Piedmont section of the Carolinas and Georgia and the Tennessee drainage basin above Muscle Shoals in Alabama and Tennessee.
3. The Colorado River.
4. The water powers of the Valley of California, of the western slope of the Sierra Nevada mountains.
5. The water powers of the Pacific Northwest and Alaska.

This latter region comprises the area drained by the Columbia River and its tributaries, and the coastal streams of British Columbia and Alaska.

The water powers of Mexico and Central America, while large in the aggregate, are isolated, and will not be given special discussion.

The economic analysis in each case is preceded by a brief description of the drainage basins and the industrial development of the region in which these water powers are located.

IV

THE ST. LAWRENCE DRAINAGE BASIN

Industrial importance of the area Description of the principal streams. The Niagara River. The potential water power of the Niagara River. The St Lawrence River. Potential water powers of the St Lawrence Gain by regulation The tributaries of the St Lawrence Summary of the power resources. Problems of the area The power situation in New England Power demand in New York Power requirements of eastern Ontario Summary of power demands The economic problems of power utilization. Plans for the development of the St. Lawrence River Hydro power from Quebec Political and administrative problems of the area The International Joint Commission The question of the export of power Special problems of the Niagara River.

THE distinctive feature of the northeastern water power area is the concentration of large potential water power resources in one large drainage system. Probably 90% of the potential water power of this area is located on the Niagara and St. Lawrence rivers, and the principal tributaries of the latter—the Ottawa, the St. Maurice, and the Saguenay. The singular legal and political status of these powers, the economic situation of the locality in which they are found, the unequal political and geographic distribution of power sites and power consuming areas, place the resources of this region in a peculiar category, requiring a policy of administration and development applicable to this region alone.

INDUSTRIAL IMPORTANCE OF THE AREA

Unlike many of the water power sites of the United States and of other parts of the world, the vast resources of this region are located in the heart of a concentrated industrial and manufacturing district. The market for power is large. A brief survey of the population and resources and the manufacturing facilities of the regions shows how great is the industrial concentration of this area. On the Ameri-

can side in New York and the New England states there are about 30,000,000 people, or 25% of the population of the United States, and in the Canadian provinces of Ontario and Quebec there dwell nearly 5,300,000 people, or practically 60% of the total population of Canada. By far the greater proportion of the population of the two Canadian provinces is in the south near the St. Lawrence River and on the shores of Lake Erie and Lake Ontario.

New England and New York produced, in 1926, about 16,000,000,000 kilowatt hours of electrical energy, or nearly one-fourth of the total in the United States, and the Laurentian and Maritime provinces of Canada have an installed capacity of over 3,000,000 horsepower, or 82% of the total for Canada. Here also in the Canadian provinces is found 11,850,000 potential hydraulic horsepower, or two-thirds of the water power resources of the Dominion available at ordinary minimum flow. With the coal of Pennsylvania and neighboring states, the combined power resources of eastern Canada and northeastern United States represent the greatest concentration of power possibilities in the world.

DESCRIPTION OF THE PRINCIPAL STREAMS

The St. Lawrence Valley may be characterized as a distinct geographic province separated from the prairie provinces of Canada by an inhospitable Laurentian upland. It constitutes a distinct economic and industrial region closely associated with New York and New England on the American side of the border. By far the greater portion of the drainage basin lies on the Canadian side of the international boundary, and only a narrow strip of land in New York and New England is drained by the tributaries of the St. Lawrence. This river is the heart of the water power resources of the area. Not only is this true of the total potential power available but also of the concentration of this power in large sites. The value of these power sites

is still further enhanced by reason of the remarkably constant flow of the river throughout the year. Except for the power sites on the St. Mary's River draining Lake Superior into Lake Huron, practically the entire power possibilities are located on the Niagara River at the Falls and in the upper reaches of the St. Lawrence River.

THE NIAGARA RIVER

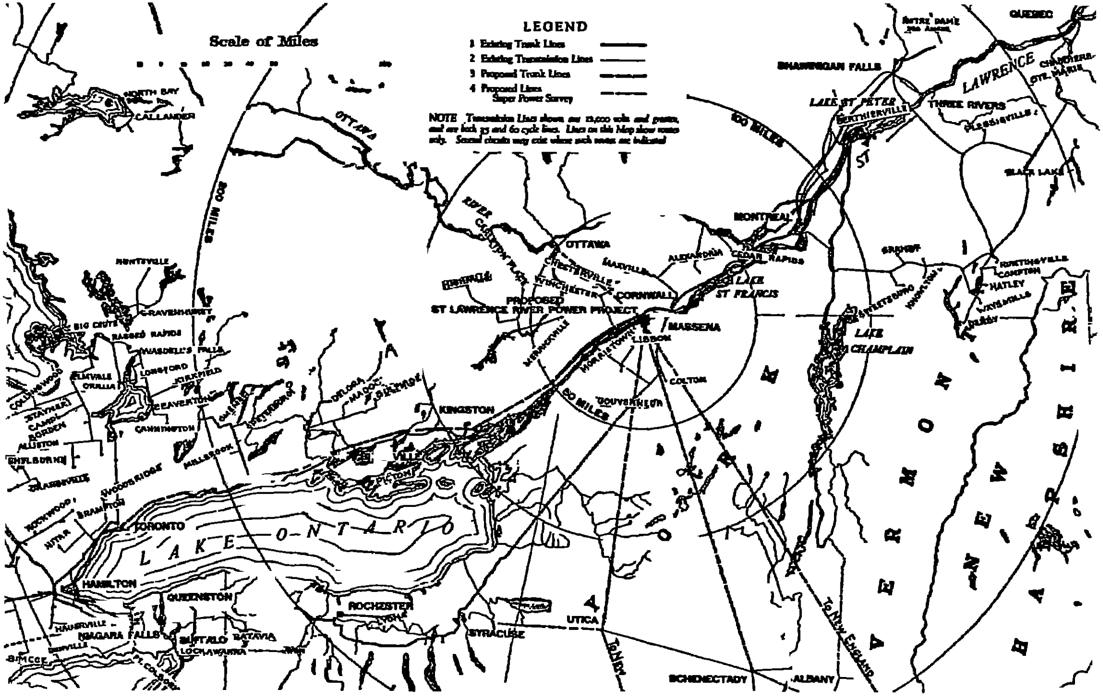
The Niagara River connects Lake Erie and Lake Ontario, the waters dropping over the Niagara escarpment in their course. Niagara Falls is probably the most widely known of America's potential water powers. Its complete development has been both urged and opposed depending upon what was most important in the point of view of the individual expressing the opinion, that is, water power or scenic beauty.

As a water power site it possesses the following characteristics, which must be taken into account when its development is urged.

It is on an international stream. No development or utilization of the power can be undertaken without the consent of Canada. This implies a treaty with the Canadian Government, and treaties can be formulated only by Congress. Hence, it is not under the jurisdiction of the Federal Power Commission, although it is likely that the administration of any water power developments authorized by treaty will be delegated by Congress to the Federal Power Commission.

Niagara Falls, because of its scenic beauty, is regarded by the public as property belonging to all, and any policy of stream development must include as part of its plan the preservation of this scenic beauty.

The Niagara, a notch in the edge of a huge drainage basin, has a remarkably constant flow. The variation in flow did not exceed 11.5% in 1923. The four interconnected lakes acting as storage reservoirs serve to equalize the erratic rainfall.



Report of the Hydro-Electric Power Commission of Ontario, 1925, Plate 13

Figure 6: Present transmission systems of Ontario and Quebec, Canada, and northeastern United States, and proposed new trunk lines.

The drop between Lake Erie and Lake Ontario is 326 feet, of which 316 feet is concentrated in a distance of 10 miles, distributed as follows:

The drop in 2 miles from the Chippewa-Grass Island Pool to the Falls is	52 feet
Mean drop at Falls	164 feet
Drop in 8 miles below Falls	100 feet
Drop in 10 miles of Niagara River	316 feet

The average flow is 205,000 cubic feet per second.

This potential water power site, the largest in the eastern United States, is in close proximity to a thickly populated industrial region, so that there is an easily developable market for electric power.

The existing water power plants are located in a position favorable to low costs. They have no money invested in lands for reservoirs, dams for storage water, or auxiliary steam equipment.

THE POTENTIAL WATER POWER OF THE NIAGARA RIVER

The theoretical horsepower available with a flow of 205,000 cubic feet per second over a drop of 326 feet is somewhat over 6,000,000 horsepower. Even without legal restrictions this theoretical maximum could not be attained, since it would be impossible, in actual practice, to utilize the entire drop. There are, moreover, treaty restraints which limit the power development to a considerably smaller figure.

THE ST. LAWRENCE RIVER

Almost the entire potential water power resources of the St. Lawrence River are concentrated in a stretch of the river extending from Galops Rapids, 65 miles below the foot of Lake Ontario, to the city of Montreal. In this stretch of 115 miles the St. Lawrence descends approximately 224 feet and has a normal flow of 247,000 cubic

feet per second[1] Except for the diversion canals, it serves as the outlet for the vast drainage basin in which are included five natural reservoirs, the Great Lakes. It also serves as a highway of commerce between the grain-producing sections of the United States and Canada and the markets of the east coast and of western Europe. True, this highway is of secondary importance and useful only for a part of the year, yet its possibilities are such that engineers have become interested in the means of its improvement. The most stupendous project so far advanced is the deepening of this waterway to give access to the sea. While the merits of this proposal will not be discussed here, yet a study of the water power possibilities of the St. Lawrence cannot be undertaken without reference to the navigation problems.

The proposed St. Lawrence-Waterway-to-the-Sea, in a narrow sense, may be regarded as the improvement of the rapids portion of the river between Galops Rapids and Montreal to accommodate ocean-going vessels drawing from 25 to 30 feet of water. Such a deep waterway, if at all feasible, is justified only if the improvement contemplates opening the sea lands to the interior as far as Duluth, Port Arthur, and Chicago. Hence, any power development that affects any part of the lake system must take into account the question of navigation.

The fall of the river on the international boundary is 92 feet, of which 91 feet is in the lower 48 miles from Galops Rapids to St. Regis, there being a fall of but one foot in the 65 miles from Lake Ontario to Galops Rapids. The Long Sault Rapids, with a fall of 48 feet, extend for about 12 miles along the lower end of this section. From St. Regis to ocean navigation at Montreal there is a fall of about 130 feet in a distance of about 70 miles, of which 129 feet is concentrated in two stretches of 14 and of 8½

[1] *Statement and Engineering Report of the Hydro-Electric Power Commission of Ontario Submitted to the International Joint Commission Respecting the Proposal to Develop the St Lawrence River*, 1925, p 25.

miles each, the former including Coteau, Cedar, and Cascade Rapids, in which the fall is 84 feet, and the latter including Lachine Rapids, in which the fall is 45 feet.

POTENTIAL WATER POWERS OF THE ST. LAWRENCE

The dependable volume of water flow is the determining factor in estimating the power potentialities of the St. Lawrence River. In its natural condition the mean monthly volumes vary from 190,000 second-feet to 320,000 second-feet. With the use of regulating works at Rapide Plat it is estimated that the dependable flow of water could be increased to 210,000 second-feet, and with coordinated regulation of all the lake reservoirs the dependable flow could be increased to 230,000 second-feet less 10,000 feet diverted by the Chicago drainage canal, or a net flow of 220,000 second-feet. Upon a basis of 210,000 second-feet the potential energy available in the rapids section of the river is computed by the engineers of the United States Army as shown in Table 9.

TABLE 9

ESTIMATED HORSEPOWER ON THE ST. LAWRENCE*

Site	Estimated Horsepower	Head
Canadian		
Lachine Rapids	860,000	30
Côteau, Cedars, Split Rock, Cascades	1,560,000	82
Total	2,420,000	112
International		
Long Sault Rapids, initial	1,464,000	88
Long Sault Rapids, later	180,000	
Total	1,644,000	88
Rapids Section		
Grand Total	4,064,000	200

* Francis C. Shenehon, "The St. Lawrence Waterway to the Sea," *Proceedings of the American Society of Civil Engineers*, Vol. 51, No. 7, September, 1925, pp. 1274, 1275

These estimates are based on a dependable flow of 210,000 second-feet with an operating efficiency of 88%, which is the performance of the new units at Niagara Falls.

GAIN BY REGULATION

Studies of the movement of water in the Great Lakes indicate that by the installation of regulating works which will include all the lakes, the dependable flow of the St. Lawrence can be increased by 20,000 second-feet, with a corresponding increase in the amount of potential power. The increase of power is estimated as follows:[2]

Lachine Rapids	78,000 h.p.
Côteau, Cedars, Split Rock, Cascade Rapids	141,000 h.p.
Long Sault Rapids	141,000 h.p.
Total	360,000 h.p.

The estimated cost of development on the Long Sault Rapids, which is the section of the St. Lawrence River upon which the first installation is contemplated, is $103 per horsepower, and the price at which current can be sold is 3.67 mills per kilowatt hour, which is less than the rate at which Niagara power is now being sold.[3]

THE TRIBUTARIES OF THE ST. LAWRENCE

The principal rivers in the Province of Quebec, other than the St. Lawrence River, which may be considered as sources of water power for New England are the Ottawa, St. Maurice, Saguenay, and St. Francis.

The total available continuous power on these rivers is about 5,000,000 horsepower, of which about 700,000 is now developed and about 600,000 is under construction. Somewhat over 300,000 horsepower of the water power now

[2] F. C Shenehon, *op cit.*, p. 1279.

[3] *Ibid.*

developed in the Province of Quebec is used in the pulp and paper industry. It is planned to use a considerable portion of the power now being developed for the same purpose.

Large storage reservoirs have been developed on the Ottawa and St. Maurice rivers, which have a considerable equalizing effect on their flow. The Saguenay River is now under development, both as to storage and power, at the outlet of Lake St. John. The ultimate development at this point will produce about 1,000,000 continuous horsepower.

The 16 principal undeveloped water power sites on the Ottawa, St. Maurice, and Saguenay rivers, which will be affected by the storage development on the headwaters of these rivers, have an estimated possible continuous output of about 2,500,000 horsepower.[4] This includes one site on each of these three rivers which is now being developed. All of this 2,500,000 continuous horsepower lies within a radius of about 450 miles from the approximate center of the power demand of New England, that is, eastern Massachusetts.

SUMMARY OF THE POWER RESOURCES

The total water power resources of the St. Lawrence drainage basin which come within the range of economic utilization may be summarized as follows:

River	Potential H.P.
Niagara	6,000,000
St. Lawrence	4,000,000
Tributaries of the St. Lawrence	5,000,000
Total	15,000,000

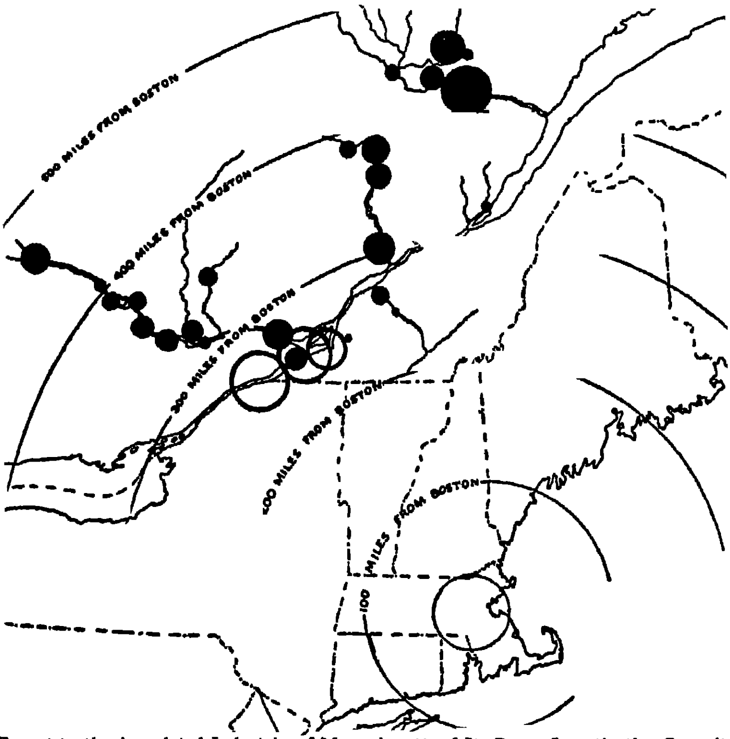
By far the greater proportion of these water powers are under Canadian or joint international jurisdiction, and many

[4] *Report to the Associated Industries of Massachusetts of Its Power Investigating Committee,* April, 1924, p. 128.

of the important power sites are at a considerable distance from the principal industrial centers.

PROBLEMS OF THE AREA

The problems that arise in connection with the development of these sites are political and economic. The economic problem resolves itself into finding a market for the power and then developing the power at a delivered cost equal to or less than that of steam. The political problems center around the necessity of an agreement between the American and Canadian governments regarding the manner



Report to the Associated Industries of Massachusetts of Its Power Investigating Committee, January, 1924, Plate 17.

Figure 7· Power possibilities on the St. Lawrence and in eastern Canada.

of development and disposal of the power satisfactory to both parties. These problems will be considered separately after reviewing briefly the power problems of New England, New York, and the Canadian provinces.

THE POWER SITUATION IN NEW ENGLAND

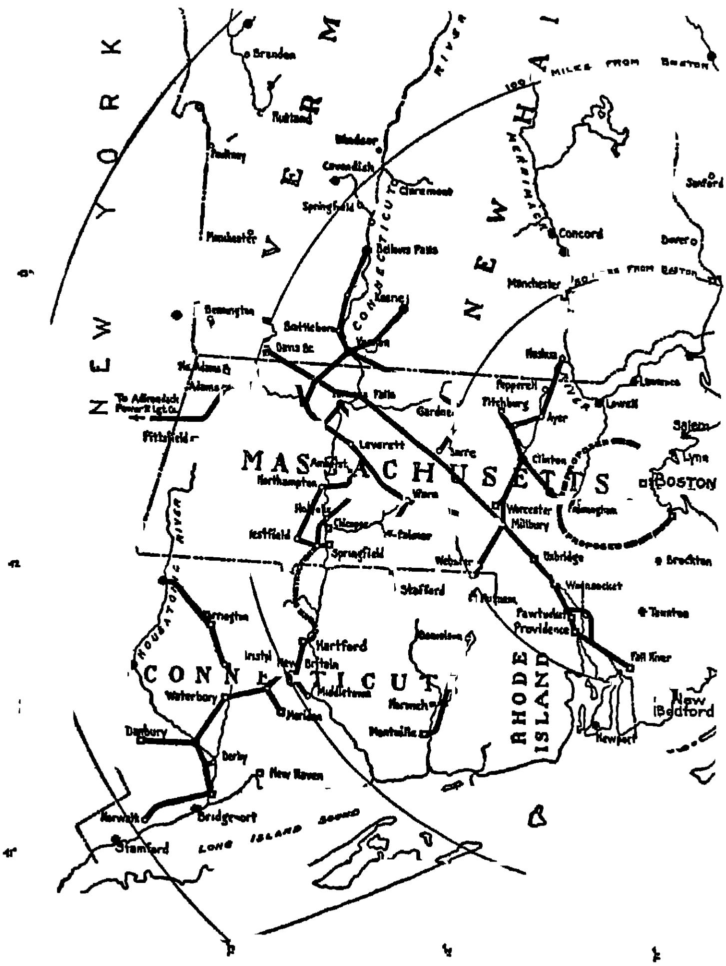
The total energy used in New England in 1922 (except in steam locomotives) was about 7,500,000,000 kilowatt hours,[5] of which about one half was generated by the industries themselves and the other half by the public utilities. Of this total about 2,200,000,000 kilowatt hours were generated by steam power.

The energy used in 1922 in Massachusetts, New Hampshire, and Rhode Island, centering about eastern Massachusetts, was about 4,900,000,000 kilowatt hours, of which the public utilities produced about one-half. Of the total about 1,000,000,000 kilowatt hours were produced by water power and the remainder from fuel.

Judging from the past, the total power requirements for New England 10 years hence are likely to be at least 15% and possibly 20% more than they are now. The rate of increase of the loads on the central stations is greater than the rate of increase of the total power demands, thus showing that the public utilities are taking over a portion of the load of the industries, the power for which was formerly generated by the industries themselves. As existing private steam plants wear out, they will continue to be replaced by power purchased from public utilities, especially in those industries which do not have important uses for exhaust steam.

It is expected that on an average for the next 10 years the load on the public utilities will increase each year by the following amounts, which may be regarded as a conservative estimate.

[5] *Report to the Associated Industries of Massachusetts of Its Power Investigating Committee*, April, 1924, p. 35

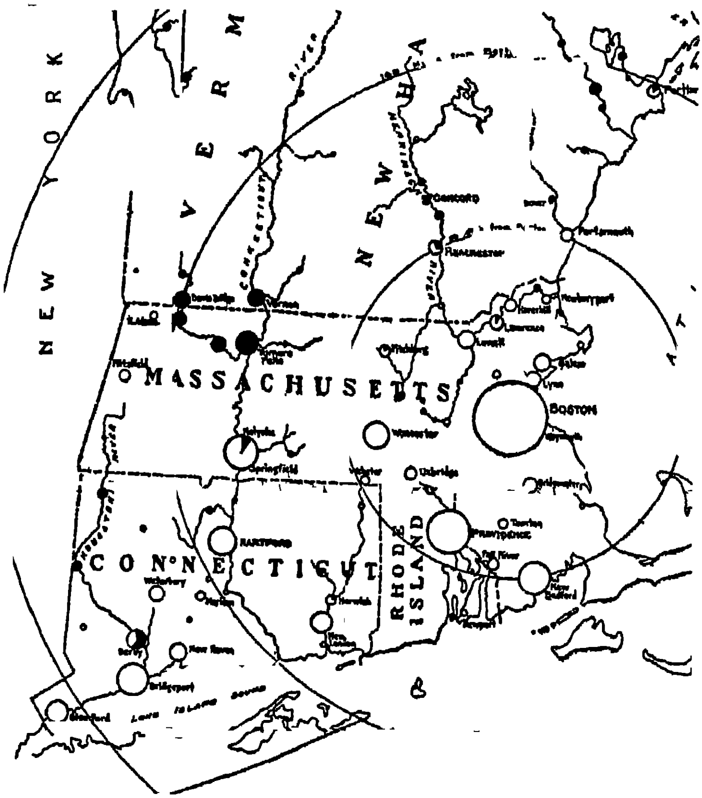


Report to the Associated Industries of Massachusetts of Its Power Investigating Committee, January, 1924, Plate 22

Figure 8: Principal interconnected transmission lines in New England (66,000 volts.)

For the Massachusetts–New Hampshire–Rhode Island group centering around eastern Massachusetts, 90,000 kilowatts net additional capacity will be required and 190,000,000 kilowatt hours generated; for all New England

140,000 kilowatts and 300,000,000 kilowatt hours.[6] This would mean that by 1931 approximately 1,400,000 kilowatts of central station capacity must be added to that already existing in New England, in addition to replacements.



Report to the Associated Industries of Massachusetts of Its Power Investigating Committee, January, 1924, Plate 11.

Figure 9: Capacity of generators in the lower New England section.

To electrify the additional railroad trackage, on which electrification would be desirable in the near future, would require about another 1,000,000 kilowatts of station capacity and 2,000,000,000 kilowatt hours per year after the electri-

[6] *Ibid.*, p 36.

fication is accomplished. The limiting factor in such electrification is the financial condition of the railroads.

The question is: Where can the necessary increase in power be obtained at reasonable costs? There is about 860,000 horsepower of undeveloped water power in New England at sites where 1,000 horsepower or more is available for 60% of the time.[7] If it could all be fully developed for 50% load factor, this would require a station capacity of 1,720,000 horsepower and would produce about 4,830,000 kilowatt hours. This would be sufficient to take care of the requirements for several years, not considering the electrification of the railroads; but unfortunately about three-quarters of this undeveloped power is in Maine, and under the existing laws cannot be exported. The power resources in the remainder of New England amount to about 160,000 kilowatts, equivalent to about 1,200,000,000 kilowatt hours. Most of this power will not be developed in the near future because of the high cost of development and of delivered current. It appears that in all New England, including Maine, enough could be developed at a reasonable cost to produce about 3,000,000,000 kilowatt hours, and of this only a small portion is in the Massachusetts–New Hampshire–Rhode Island district, the area where it is most needed.

Some additional water power can be obtained from the small undeveloped resources, and used either locally or as feeders to larger systems. Such additional surplus power can be supplied at Lawrence, Holyoke, and Turners Falls. A greater amount of power can be obtained from some existing properties by redeveloping and getting greater efficiency and capacity. The total from all such sources is relatively small compared with the total power requirements for New England's growth, although important to individual plants.

In view of the above it appears that the great bulk of the power for New England's additional requirements, par-

[7] *Ibid.*

ticularly in the district centering about eastern Massachusetts, must come from the following:

1. Large public service steam plants, located not far from the load centers so as to obtain coal at the lowest rates, and containing large units which are interconnected in order to run on high load factors at minimum operating costs, or

2. The use of large water powers in Canada to supplement such steam plants in New England, provided proper arrangements can be made for the export of electric current.

There are two potential sources of such water power, the large developments on the tributaries of the St. Lawrence in Quebec, in the early construction of which private capital is already engaged, and which can be economically developed in progressive steps, and the still much larger developments on the St. Lawrence River.

In view of the distances over which this power would have to be transmitted (from 275 to 425 miles), and the cost of transmission lines, it would not be economical to attempt to bring any of this power into Massachusetts, unless in quantities approximating 1,000,000,000 kilowatt hours a year within a year or two after such lines are completed. It is essential that a sufficient market be developed to utilize fully this output of one or more of the plants. The cost of the necessary transmission lines and other auxiliary equipment for a 1,000,000,000 kilowatt hour project on a 50% load factor basis, together with the loss of power in transmission and delivery to customers, would make the cost of power, delivered to the users of large quantities in eastern Massachusetts, probably not over 1¼ cents a kilowatt hour.

POWER DEMAND IN NEW YORK

The power requirements in New York State are also significant. New York City is about equidistant from the Long Sault Rapids and from Niagara Falls—300 miles away. Schenectady is 160 miles from the Long Sault Rapids and 260 miles from Niagara Falls. Albany is 175 miles

from the Long Sault. In 1922, the Greater New York district had a maximum of about 1,418,000 horsepower. The increase in power consumption in New York public utilities is shown in Table 10.

TABLE 10

POWER CONSUMPTION IN THE GREATER NEW YORK DISTRICT*

Year	Kilowatt Hours Used	Increase
1921	6,170,106,000	.
1922	7,420,778,000	12 0%
1923	8,772,289,000	11 8
1924	9,288,569,000	10 6
1925	10,050,000,000	10 3

* *Electrical World*, January 2, 1926, Vol. 87, No 1, p. 10

The water power resources of New York State, other than its share on the international streams, aggregate about 1,200,000 horsepower, located principally in the Adirondack Plateau. Of this about 900,000 horsepower is developed either as hydraulic or hydroelectric power.[8] It is evident, then, that the major portion of New York's internal water power resources is utilized. The existing plants are not, however, developed to their maximum efficiency. At the time of installation the immediate needs and not the ultimate possibilities of the stream were given consideration. Hence, sites have been developed at less than their potential power, and opportunities for stream diversion from one watershed to another with resulting increase in head have been neglected. The rights of existing properties will make it expensive to redevelop the rivers for higher efficiency.

Topographic conditions in the Adirondacks are favorable to the construction of storage reservoirs, but for several reasons storage has not been developed. The owners of power plants, mostly pulp mill operators, do not need a regulated flow. Grinding of the pulpwood can be done during flood

[8] *Proceedings of the American Society of Civil Engineers*, Vol. 48, No. 9, November, 1922, p. 1741.

season. Furthermore, until 1916, the State Preserve, of which parcels are found in each storage site, could not by law be used for such purposes. However, the recent public interest in water power development, together with changes occurring in the paper industry, is affecting the status of water power developments. The gradual discontinuance of pulp grinding in New York State is resulting in the conversion of many mechanical water power plants into hydro-electric installations. This change is also making possible a more effective development of an entire stream. Nevertheless, the aggregate output of electrical energy from the interior streams can supply but a small part of New York's power needs.

POWER REQUIREMENTS OF EASTERN ONTARIO

The Hydro-Electric Power Commission of Ontario, in 1924, estimated that it would be necessary to provide new sources of electrical power amounting to more than 400,000 horsepower by 1931, which would be increased to over 1,100,000 horsepower by 1936.[9] The estimated annual consumption by 1931 would be an additional 2,300,000,000 kilowatt hours based on a 65% load factor.

SUMMARY OF POWER DEMANDS

The present production and future demands are summarized in Table 11. This increase of approximately 5 billion Kilowatt hours by 1931 would require an installed capacity of nearly 1,000,000 additional kilowatts.

Reviewing power demand in relation to power supply, two outstanding features may be noted, first, the surplus of potential power on the tributaries of the St. Lawrence in Quebec, and second, the large apparent surplus of power in the St. Lawrence. This latter unutilized resource appears as a surplus only when measured against present demands.

[9] *Northeast Super Power Report*, 1924, p. 5.

TABLE II

POWER CONSUMPTION IN THE ST. LAWRENCE DISTRICT*

Section	1922 Production in Millions of K.w. Hrs.	Estimated Demand in 1931 in Millions of K.w. Hrs.
New England	4,525	5,894
New York	7,934	10,800
Ontario	2,800	3,960
Total	15,259	20,654

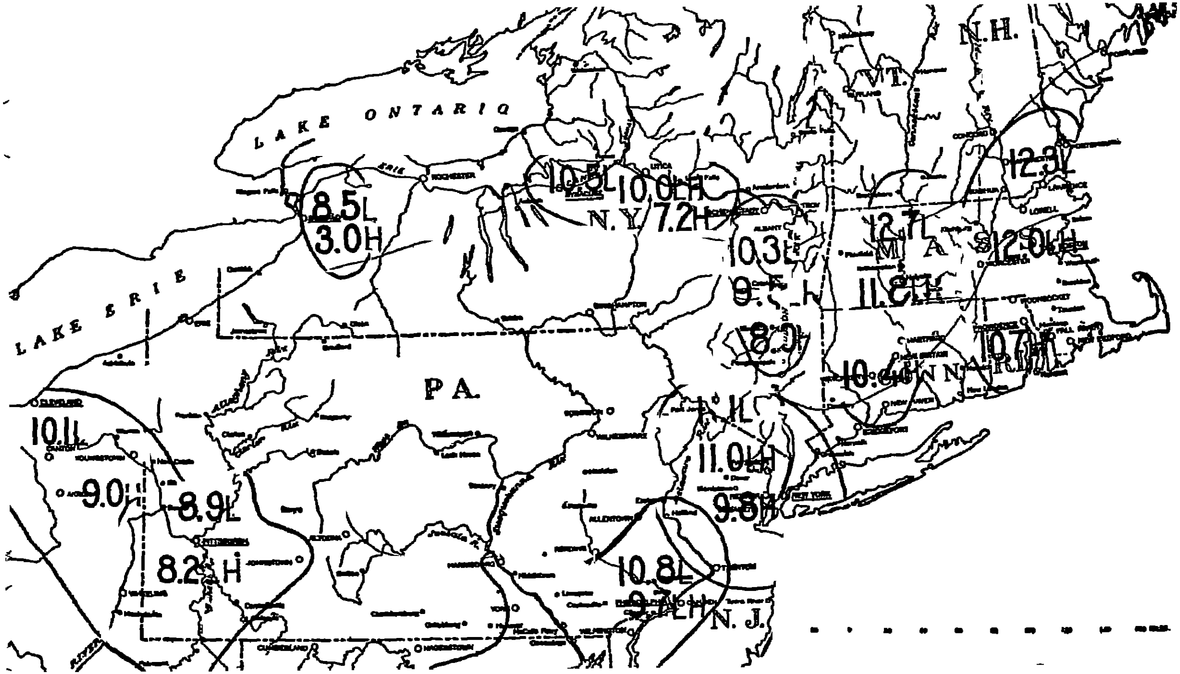
* *Statement and Engineering Report by the Hydro-electric Power Commission of Ontario Submitted to the International Joint Commission Respecting the Proposal to Develop the St. Lawrence River*, 1925, p. 20.

Taking into account, however, the time which will be required to develop the river, together with the treaty limitations imposed upon the use of Niagara power, it is reasonable to assume that this surplus can be absorbed by the expected increase in demand in the next decade. This assumption presupposes that future demand will be met by development of St. Lawrence power and not by the erection of new steam stations.

THE ECONOMIC PROBLEMS OF POWER UTILIZATION

The Northeast Super Power Committee, in a study made in 1924, worked out in considerable detail the costs of current from local steam plants, mine-mouth steam stations, local hydro plants, and St. Lawrence hydro plants. The cost of delivered current at the important load centers by (1) all local steam generation, (2) a combination of local steam and local hydro, and (3) local steam and local hydro combined with base load power from Niagara or the St. Lawrence, were also analyzed. By local hydro is meant the scattered water power of Massachusetts, Connecticut, and New York.

Figure 10 shows the comparisons of cost for the principal districts. The desirability of developing all the principal



Super Power, Northeast section of the United States, Northeast Super Power Committee, Plate 17.

Figure 10: Comparison of cost of power from various sources

hydroelectric possibilities in the St. Lawrence basin is evident from these figures.[10]

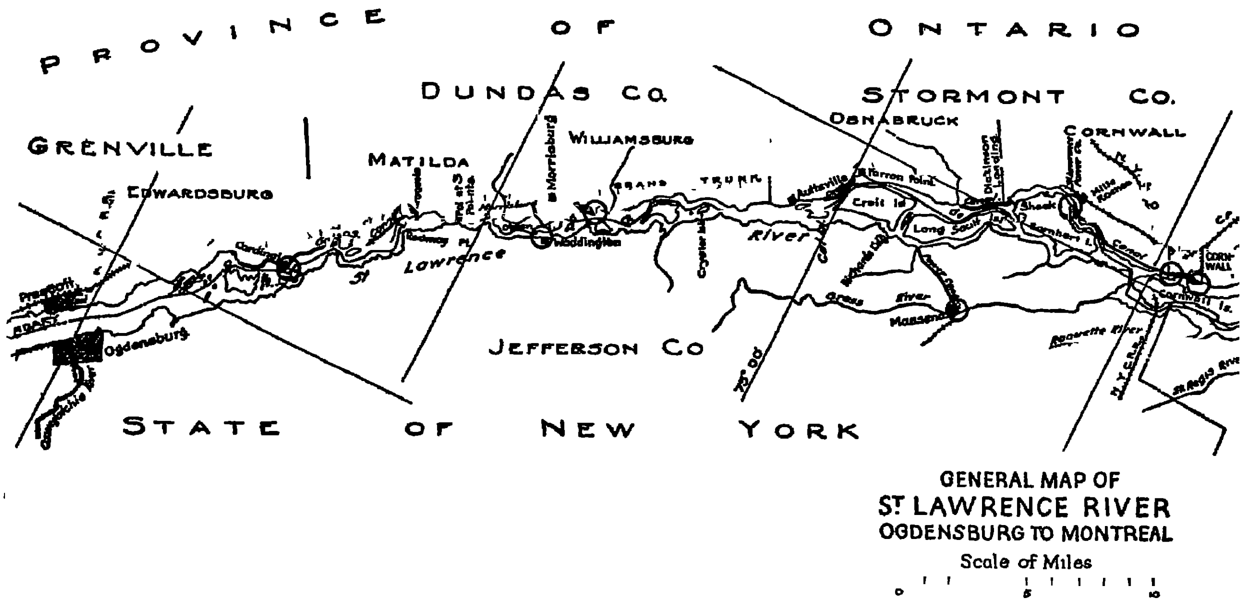
PLANS FOR THE DEVELOPMENT OF THE ST. LAWRENCE RIVER

The Hydro-Electric Power Commission of Ontario has submitted three tentative plans for the development of the power section of the St. Lawrence River. These plans take into consideration the utilization of the river for navigation purposes also. One plan calls for a single-head development, because this method would concentrate the entire available fall at the foot of the Long Sault, where the main dams and power house would be situated. There would also be a control dam at the Rapide Plat to regulate the outflow from Lake Ontario. The normal operating head of the proposed power house would be 74.5 feet. At the head of the South Sault channel there would be a power house to utilize, under a head of about 28 feet, that part of the flow of the river diverted to the power plant at Massena, New York. The total development would produce about 1,492,000 continuous electrical horsepower at a cost of $95 per horsepower.

In the second plan, the development would be carried out in two stages, the upper of which would include the fall in the Galops Rapids and the Rapide Plat, while the lower would include the fall in the vicinity of Farran Point and at the Long Sault. The greater part of the fall available in the slope in the intervening river stretches would be utilizable

[10] The figures in Figure 10 show costs in mills, per kilowatt hour, for power from (L) local steam plants only, (LH) local steam and local hydro, (H) local steam and Niagara or St Lawrence power The basis is the predicted load for 1935, using the most economical proportion of local hydro, St Lawrence-Niagara, or mine-plant power, in conjunction with power generated locally by steam For instance, in the New York territory Niagara and St Lawrence power will be the cheapest, while, because of the distance from the coal field, it will not be economical to transmit the power from plant-at-mine-steam The desirability of developing our principal hydroelectric possibilities is clearly shown

For a detailed analysis of the cost of steam power and power from St Lawrence, see the "Report of the Northeast Super Power Committee," *Superpower Studies*, May, 1924.



Report of the Hydro-Electric Power Commission of Ontario, 1925, Plate 1.

Figure 11: General map of St. Lawrence River, Ogdensburg to Cornwall

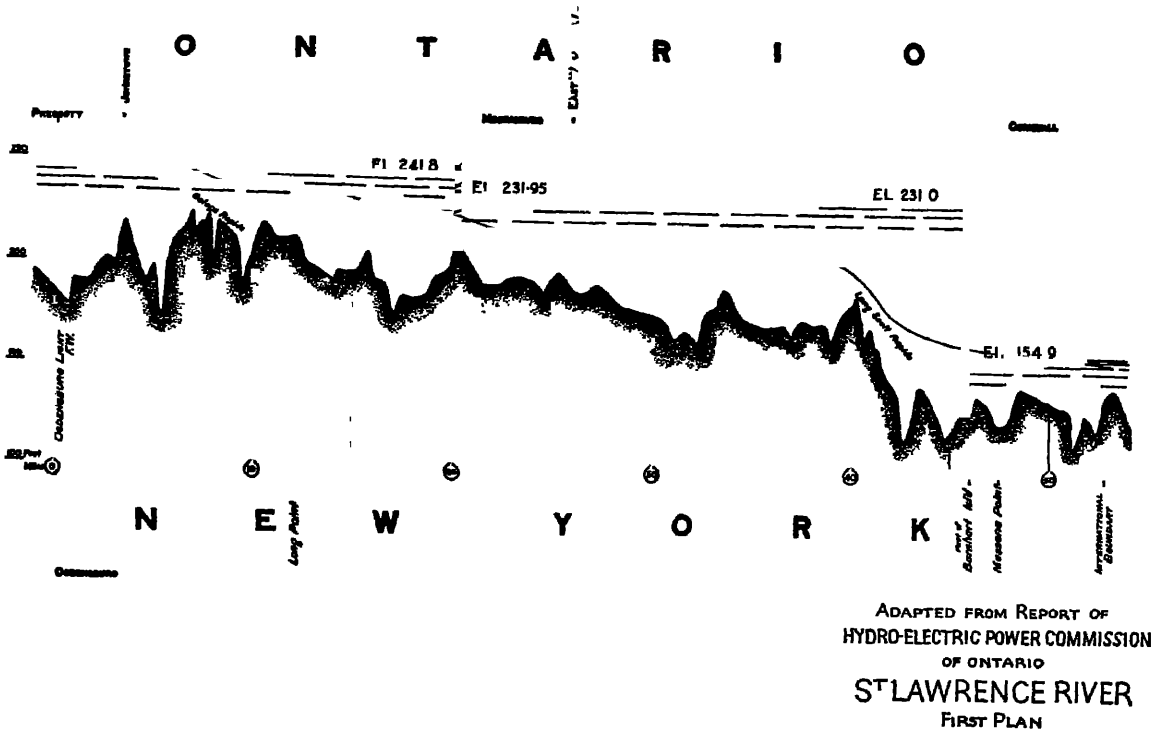


Figure 12: Diagram of first plan for the development of the St. Lawrence River.

in either one plant or the other. This may be styled a double-head development. The total development would produce about 1,600,000 continuous horsepower at a cost of $96 per horsepower.[11]

The third plan submitted is also a two-stage concentration to obtain the power head, the upper dam and power house being placed at Crysler Island and the lower power house at Barnhart Island. This development would produce about 1,635,000 continuous horsepower at a cost of $95 per horsepower.[12]

On any one of these plans, it would not be necessary to carry the work to completion immediately. After an initial minimum development is made, the work required to complete the project might be advanced by gradual additions.

The cost of power from the completed developments, delivered at the terminal switchboard within a radius of 300 miles, is calculated at from one-half to two-thirds of a cent per kilowatt hour.

"These figures may be contrasted with the present average cost of steam-electric energy in, say, New York City, where—it is authoritatively stated—the cost is in the neighborhood of $60 per horsepower-year, with a load factor of about 50%. Present minimum power rates are about 1 1/3 cents per kilowatt hour, which means that the cost can scarcely be less than one cent per kilowatt hour.

"It is thus evident that the electrical power developed from the St. Lawrence River water powers would be able to replace to a very large extent steam-electric power."[13]

[11] *Report of the Hydro-Electric Power Commission of Ontario to the International Joint Commission*, 1921.

[12] *Ibid*

[13] For a detailed analysis of the various plans of development and the costs, see the *Engineering Report of the Hydro-Electric Power Commission of Ontario Submitted to the Joint International Commission Respecting the Proposal to Develop the St. Lawrence River*, 1921 Reprinted with later data, 1925.

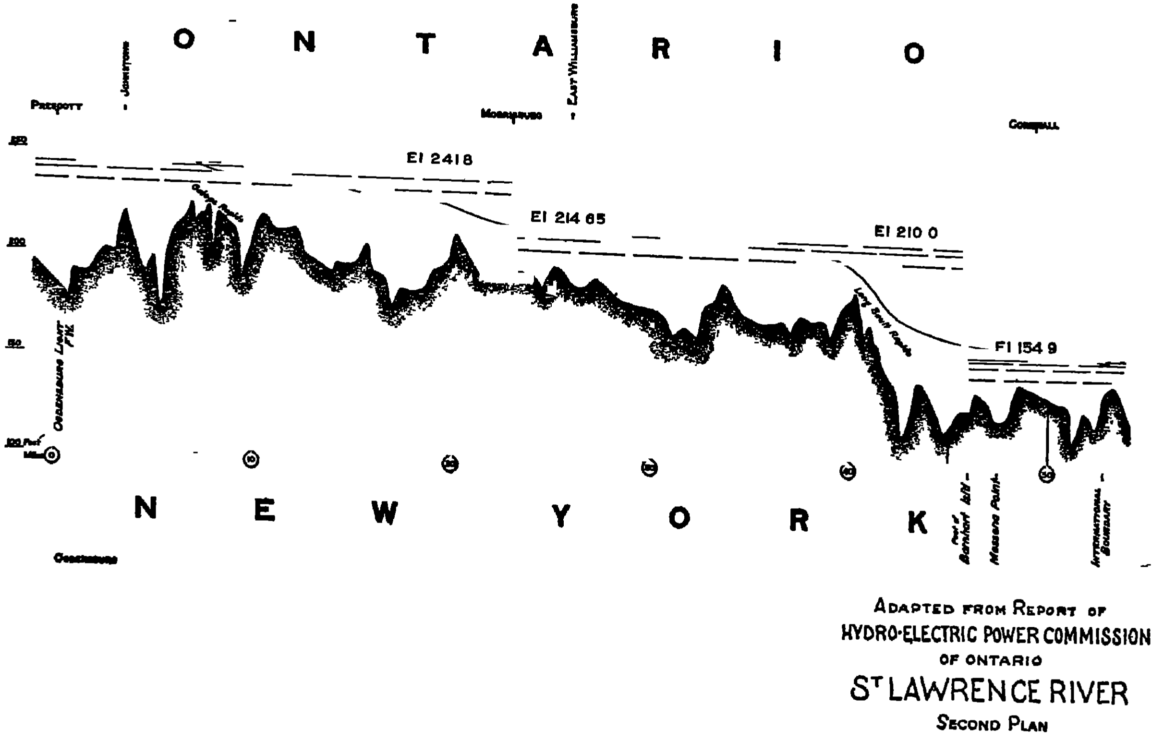


Figure 13: Diagram of second plan for the development of the St. Lawrence River.

HYDRO POWER FROM QUEBEC

The development of the St. Lawrence River is tied up with the projected canalization of this river for deep sea navigation, and cannot be undertaken until suitable international agreements and legislation are carried out. The development of the first of these powers would probably require from six to eight years after the Canadian and United States governments had agreed upon a plan of procedure and the financing of the undertaking, for any part of the river forming the international boundary or for that part wholly in Canada. It is evident that even if favorable government action were actively begun at once, no power from the St. Lawrence River could be hoped for in less than ten years. To supply the immediate needs of the American consumers, it would seem a better plan to make a beginning with power derived from the smaller water power sites of the Ottawa, St. Maurice, and Saguenay rivers, rather than from the St. Lawrence power sites. The Power Investigating Committee of the Associated Industries of Massachusetts has determined that power from Quebec is economically available only if at least 1,000,000,000 kilowatt hours are purchased annually within a reasonable time after the construction of the plant. In this connection two questions immediately arise:

1. Can this quantity of energy be marketed in New England within a reasonable time?

2. Will the Canadian and Provincial governments give assurance that this amount of energy will be allowed to be transmitted into New England for a sufficient period of years, so that the cost of the undertaking may be authorized at a reasonable rate?

The first of these questions can be answered as follows:

It is found that the section centering on Worcester or Framingham, and including Massachusetts, Rhode Island,

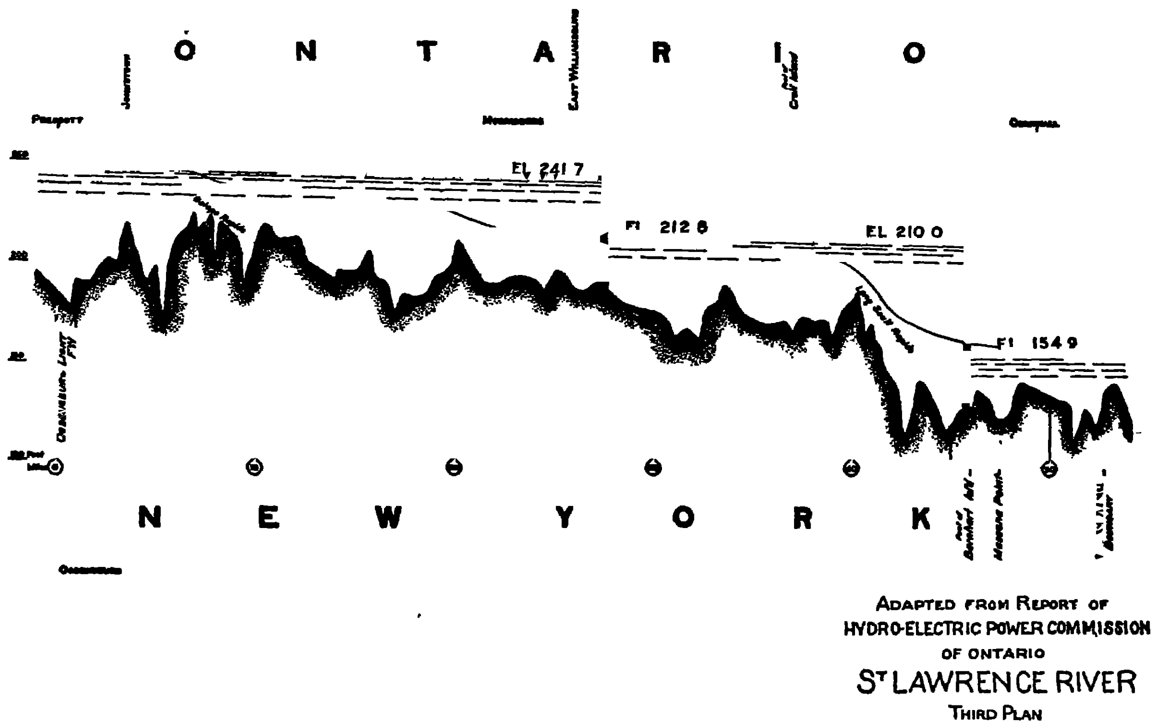


Figure 14: Diagram of third plan for the development of the St. Lawrence River.

and southern New Hampshire, produced about 3,835,000,000 kilowatt hours from steam power in 1922, and that the natural increase of power demand for central station power in this section will call for approximately another 1,900,000,000 kilowatt hours in the next 10 years. If Connecticut were added, since it also is already tied in with Massachusetts and Rhode Island by means of interconnected transmission lines, the 1922 steam power figure is found to be 4,935,000,000 kilowatt hours. In view of the natural growth in power demand, the natural replacement of existing steam plant equipment due to obsolescence, breakage and wear, the uneconomical steam power equipment still being used, and the margin between the cost of power produced by most of the modern steam plants under present conditions and that estimated for hydroelectric power from Quebec, it appears that 1,000,000,000 kilowatt hours from this source could be marketed within a reasonably short period after it became available.

The second question outlined above can probably not be answered until the problem is specifically presented to the Canadian and Quebec parliaments. The arguments that have been advanced for and against the exportation of power are discussed under the section on political problems.

POLITICAL AND ADMINISTRATIVE PROBLEMS OF THE AREA

The international character of the streams upon which the major water power sites are located necessarily means the subordination of the authority of the Federal Power Commission of the United States and the Hydro-Electric Power Commission of Ontario to an international authority.

THE INTERNATIONAL JOINT COMMISSION

The sole power for regulating the use of the streams flowing across or between an international boundary lies with the Government of the United States through its treaty-

making power. Treaties are made by the President and approved by the Senate. Laws necessary for carrying out the terms of the treaty are enacted by Congress. The utilization of an international stream can be accomplished only when the countries involved have made a treaty. Such a treaty implies a unity of will existing among the signatory powers concerning a course of action.

In order to dispose of the problems that arise in connection with boundary streams between the United States and Canada a joint commission known as the International Waterways Commission was formed in 1902 consisting of six members, three from the United States and three from Canada. It was the duty of this commission to investigate and report upon the conditions and uses of the waters adjacent to the boundary line between the two countries. Since the authority granted by Congress to this commission was too limited to permit effective cooperation with the Canadian representatives, a new commission with enlarged powers for dealing with all international water rights on the frontier was created under treaty of 1909. Under this treaty the International Joint Commission was created in 1911. To this body are referred all questions that arise concerning the use and regulation of boundary waters. In January, 1920, the commission was empowered by the two governments to make a special investigation of the St. Lawrence River. In this investigation the Hydro-Electric Power Commission of Ontario cooperated by supplying data from its own investigations.

The provisions of the Federal Water Power Act affect in no degree the jurisdiction of the International Joint Commission, but the Federal Power Commission becomes the agency of the United States with authority to grant, within the limits of its jurisdiction, permits or licenses in accordance with which applicants may construct, maintain, and operate on the American side of the international boundary such power projects as may have received prior approval of the International Joint Commission.

THE QUESTION OF THE EXPORT OF POWER

The excess of relatively cheap power resources on the Canadian side of the international boundary and the preponderance of power consumption on the American side naturally cause the American industrialists to look to Canada for new supplies of electrical energy.

Hence, the question of the exportation of power from Canada to the United States is causing considerable apprehension and discussion in Canadian Dominion and Provincial government circles. In 1924 the exportation of power amounted to 1,400,000,000 kilowatt hours issued on permits revocable on one year's notice. The situation is, however, very unsatisfactory for both Canadian and American interests. Canadians are as yet unable to utilize their vast power resources and are unwilling to bind their resources to American customers through long-time contracts. American interests purchasing Canadian power on yearly contracts are unwilling to invest extensively in plants whose operation is dependent upon a source of power which may be cut off at any time.

The opinions of the two divergent groups may be summarized as follows:

Those favoring exportation on long-time contracts point out that:

1. The exportation of power does not differ from that of any other natural resource such as coal, or pulpwood.

2. No restrictions have been placed by the United States on nonreplaceable raw materials such as coal.

3. Although Canada exports 1,400,000,000 kilowatt hours to the United States, she imports 20,000,000 tons of coal and more than 400,000,000 gallons of petroleum annually. In modern steam stations this amount of coal would produce 30,000,000,000 kilowatt hours of power.

4. Canada has a surplus of power over what can possibly be utilized for many years.

5. The favorable location of Canada for export of power due

to nearness of her large undeveloped water powers to the industrial districts of the United States is an opportunity for immediate profit to Canada and not a menace to its future prosperity.

On the other hand, the opponents of a policy of exportation of power on long-time contracts assert that:

1. In the territory from which it would be feasible to transmit power to New York and New England, there is not sufficient commercial water power to prevent serious power shortages in central Quebec and southern Ontario within a generation.

2. If the most desirable and largest water powers in central Canada are developed primarily for exportation purposes, the industrial progress of the country will be retarded.

3. It will never be practical to recover power once leased.

The suggested solution for a power shortage in New England and New York is the cooperative development of the Niagara and St. Lawrence rivers.

SPECIAL PROBLEMS OF THE NIAGARA RIVER

The utilization of the power potentialities at Niagara Falls requires more detailed discussion than that given to the economic problems of water power development in the St. Lawrence Basin. The total theoretical power available has been estimated at 6,000,000 horsepower (see page 48). It was mentioned that, aside from the practical impossibility of attaining this theoretical maximum in actual development, there were treaty limitations which reduced this developable figure to a still smaller quantity. On account of fears that diversions of water being made from the Niagara River both in the United States and Canada would injure the scenic beauties of Niagara Falls, Congress on June, 29, 1906, passed the Burton Act (34 Stat., 326), which limited diversions on the American side to 15,600 cubic feet per second, pending negotiations with Great Britain for the purpose of drafting a treaty to cover the regulation and control of the waters of Niagara River. The treaty was negotiated on May 13, 1910, and provided for "maximum daily water di-

verted from Niagara River for power purposes at the rate of 36,000 cubic feet per second to Canada and 20,000 cubic feet per second to the United States." This makes possible the development of approximately 1,000,000 horsepower. The installed capacities in horsepower of the several plants on the Canadian and American side of the Niagara River are as shown in Table 12.

TABLE 12

POWER PLANTS ON THE NIAGARA RIVER*

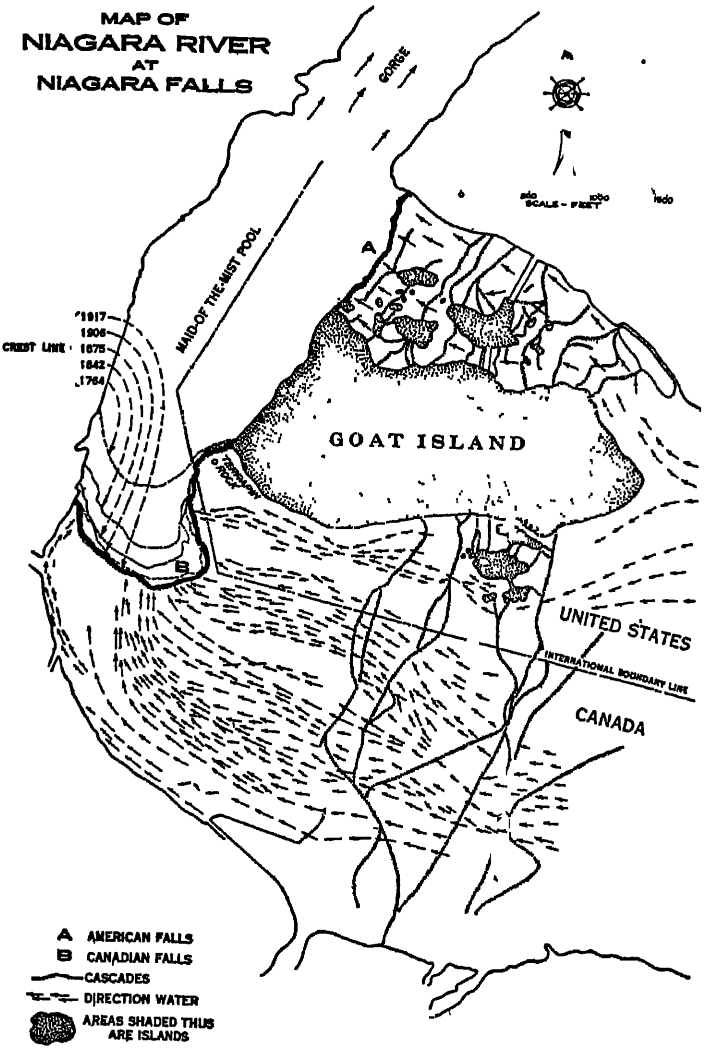
Canada	(Horsepower)
Hydro-Electric Power Commission	
Queenston plant	350,000
Ontario Power Co. plant	185,000
Toronto Power Co. plant	125,000
Canadian Niagara Power Co. plant	121,000
International Railway Co. plant	2,000
Canadian Total	783,000
United States	
Niagara Falls Power Company	
Niagara plant	105,000
Hydraulic plant	455,900
United States Total	560,900
Grand Total (United States and Canada)	1,343,900

*S. S. Wyer, *Niagara Falls, Its Power Possibilities and Preservation*, Smithsonian Institution, Publication 2820.

The continuous serving capacity of the above is about 1,000,000 horsepower since part of the equipment must be held in reserve.[14]

It is entirely feasible, however, to increase the water diversion for power purposes and, in fact, an increased diversion may be necessary to preserve the scenic beauty of the Falls. The once beautiful horseshoe-shaped crest line of the Canadian side is cutting a V-shaped gorge into the rim of the horseshoe. As shown in the map reproduced as Figure 15, the general crest line from 1764 to 1906 remained practically unchanged in shape, receding at the rate of

[14] S. S. Wyer, *op. cit.*, p. 27.



S. S. Wyer, *Niagara Falls Its Power Possibilities and Preservation*, Smithsonian Institution, Publication 2820.

Figure 15: Map of Niagara River at Niagara Falls.

TABLE 13

WATER DIVERSIONS OF THE NIAGARA RIVER*

	Cu. Ft. per Second
Natural mean flow of Niagara River	205,000
Water diversions	
New Welland Ship Canal	2,000
New York State Barge Canal	1,200
Chicago Drainage Canal	8,000
Diversion for power purposes authorized by present treaty	56,000
Minimum flow over Niagara Falls for scenic effect	50,000
Total	117,200
Water that could be harnessed	87,800

This water could develop about 2,500,000 additional horsepower, or a total of 3,500,000 horsepower from the Falls.

* S. S Wyer, *op cit*, p 27

2 inches a year. Since the latter date, however, a new gorge has been cut which is now receding at the rate of 5 feet a year. The Canadian Falls carries 94% of the water, and since this enormous flow is concentrated in the V-shaped gorge it tends to increase the rate of recession. Hence non-use, instead of preserving the scenic beauty of the Falls, will tend to hasten its destruction. The only way that this destruction can be prevented is by a redistribution of the flow so as to cover the entire crest line and reduce the flow. It is suggested by Wyer that "it will be necessary to construct artificial islands or a submerged dike above the Canadian Falls so as to prevent the concentration of the water in the V-shaped notch."[15] At the same time an increased diversion of water might be permitted which would develop an additional 2,500,000 horsepower. This is best explained by means of Table 13.

[15] *Ibid.*, p. 28.

V

WATER POWERS OF THE SOUTHEASTERN STATES

Natural resources of the area. The iron industry. The textile industries. Water powers of the South. The Tennessee River and its tributaries The economic utilization of the Tennessee River and its tributaries. Storage dams Power dams. Estimated output of power dams. Market for the power Cost of power. The water powers of the Piedmont. Developments on the Tallulah and Tugalo rivers. The Catawba River The power market. The power companies in the southeastern interconnected power system.

THE potentially large supply of water powers in that portion of the southeastern states comprising the Piedmont areas of the Carolinas and Georgia, northern Alabama, and eastern Tennessee owe much of its importance to the proximity of a large and diverse supply of industrial raw materials. Cotton, the basic raw material of the most important of the textile industries, is the means of converting a large portion of the power of streams into goods of economic value. However, cotton is not the sole basis of southern industry. Bauxite, iron ore, phosphates, and tobacco add to the list of supplies that are gradually building up a manufacturing industry. The industrial progress of these states has frequently been obscured by their importance as growers of cotton. The dominance of this plant in southern economy, ever since the invention of the cotton gin, and the importance of the crop to the prosperity of the South has received so much stress that one is prone to regard the region as purely agricultural, with cotton as the cash crop. And, indeed, such was the case previous to and immediately following the Civil War. Into this region of cotton plantations, however, industries are going with remarkable rapidity. The industrial district is easily located. Beginning in the west at Birmingham, Alabama, it extends in an easterly and north-

erly direction, including the Piedmont district of Geor
the Carolinas, and the area surrounding Danville, Virgi
Its total area is less than 50,000 square miles, thougl
contains portions of five states.

The great strides made in industrial growth in the So
are clearly indicated by an analysis of the present po
demand. The energy output of central stations has
creased from 3,000,000,000 kilowatt hours in 1921 to o
6,000,000,000 kilowatt hours in 1926, an increase of 10c
in six years.[1] In a survey made by the *Electrical World*
1925 it is estimated that 793,927 electric horsepower is
stalled in private electric generating plants, and that 2,2c
447 horsepower is in electric motors run by energy p
chased from central stations, and that 50% of industry
these states is electrified. The lumber industry is the larg
user of power, followed by the textile industry.

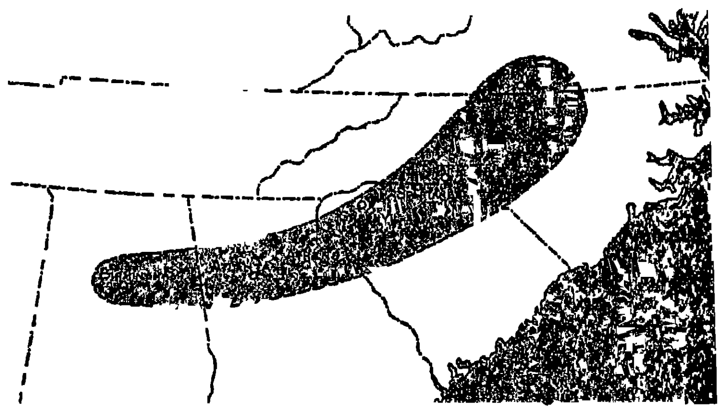


Figure 16: The industrial district of the South.

The two major manufacturing industries of the Sout
are cotton manufactures and the production of iron an
steel, although considerable progress is being made in alum
num reduction, pulp and paper making, lumber manufactur
and the products of lumber, and in the fertilizer industry

[1] *Electrical World*, Vol. 89, No. 1, January 1, 1927

THE IRON INDUSTRY

The production of iron and steel is restricted almost wholly to the Birmingham district. In 1923 the iron and steel mills of this district employed 22,000 workers. Alabama is now the third iron and steel state of the country, having pushed ahead of Illinois. Birmingham, the principal center, nearly doubled its population in the decade from 1910 to 1920. The industry mines its iron ore and coal, and quarries its limestone out of adjoining hills.

THE TEXTILE INDUSTRIES

From a modest beginning in 1880 with less than 500,000 cotton spindles until 1927 with over 18,000,000 active spindles, or nearly 50% of the total for the country, the South is gradually coming to supremacy in the spinning industry. These textile factories are concentrated between Danville, Virginia, and Atlanta, Georgia. Progress in the establishment of both spinning and weaving mills went forward since the World War in spite of the depression of 1921. The condition of the cotton spinning industry in this section as compared with the old textile center—New England—is illustrated in a striking manner by a comparison of spindle hours in the two sections. Out of a total of 76,839 million spindle hours in 1924, the South has 49,655 million, or 65%, and in 1925, when the total increased to 80,520 million spindle hours, the South's proportion rose to 71%. The drift southward can be measured by observing the change which took place from 1921 to 1923. During those two years the six New England states increased their man power by 5% and their output by 25%, while the southern district increased the total number of operatives by 25% and the value of the product increased 74%. The southern development is aided considerably by low costs of production. Power derived from the streams is probably cheaper than in New England. The cost of dwellings, foodstuffs, and

domestic fuel is considerably cheaper, so that laborers can live comfortably on a wage much lower than that in New England.

WATER POWERS OF THE SOUTH

In a report issued by the United States Geological Survey April 29, 1924, the estimated potential water power of these states is as follows:

2,944,000 h.p. available 90% of the time.
5,056,000 h.p. available 50% of the time.

Over 90% of this potential power is located in or near the industrial belt described above. The remarkable water power supply of this district is derived from a peculiar combination of natural factors. First, the mountains rise much higher than do those of the older Appalachians of the north; second, the average rainfall is greater; third, the peculiar contour of the mountains and valleys makes hydroelectric development relatively inexpensive.

The public is familiar with Mount Mitchell, in western North Carolina, rising to an elevation of 6,711 feet, the highest peak east of the Rockies; few realize the size of the great mountain mass which lies in the center of the southern Appalachians. This mass includes the Great Smoky Range to the west and the southern portion of the Blue Ridge to the east. A report of the Geological Survey states:

> The most striking characteristic of the Blue Ridge is the great difference in the slope of the opposite sides. The rivers flowing to the west into the Tennessee and the Ohio head in the gaps upon the divide and for miles flow in broad, smoothly rounded valleys before entering the narrow, drift-filled, rock-cut gorges of their lower courses; while the rivers flowing to the east plunge downward in a series of cascades, falling several thousand feet in a distance of a few miles.
>
> The latter streams can hardly be said to have valleys, but simple-shaped gorges, down which they tumble and foam until they reach the Piedmont plain, which extends along the southeastern base of the Appalachian system. Flowing into the Atlantic are the Yadkin, Catawba, Broad, Saluda, and Chatooga;

into the Gulf, the Chatahoochee and the Coosa. The New River flows to the north and enters the great Kanawha. From the western slopes of the Blue Ridge flow the headwaters of the great Tennessee River system. This drainage basin has an area of about 1,500 square miles and a fall of about 1,000 feet between its source and the North Carolina and Tennessee state line.

Geographically the water powers may be grouped as those east of the mountains in the Piedmont of the Carolinas and Georgia, and those west of the mountains located on the Tennessee River and its tributaries. A portion of the water powers in northern Alabama are located on the Gulf streams and, for purposes of economic analysis, may be associated with the Tennessee River group of powers.

THE TENNESSEE RIVER AND ITS TRIBUTARIES

By far the most important power stream of the southeastern states is the Tennessee River in its upper stretches above Dam No. 1 of the Muscle Shoals development and in its principal tributaries. The total potential power on this river system has been estimated to be as high as 4,000,000 horsepower[2] although this is based largely on reconnaissance surveys. Not until the detailed survey now being conducted by the War Department is completed will accurate data be available.

The Tennessee River has its headwaters in the mountains of Virginia, Kentucky, and North Carolina. It is formed by the junction of the French Broad River and the Holston River at a point about 4½ miles above Knoxville, Tennessee. The Tennessee River flows southwest across the eastern part of the state into northern Alabama, thence generally westward to the northwest corner of this state, where for a short distance it forms the boundary line between Mississippi and Alabama, and then crosses Tennessee and Kentucky to the Ohio River at Paducah. The total length of the river is 652 miles. The distance from Knoxville to

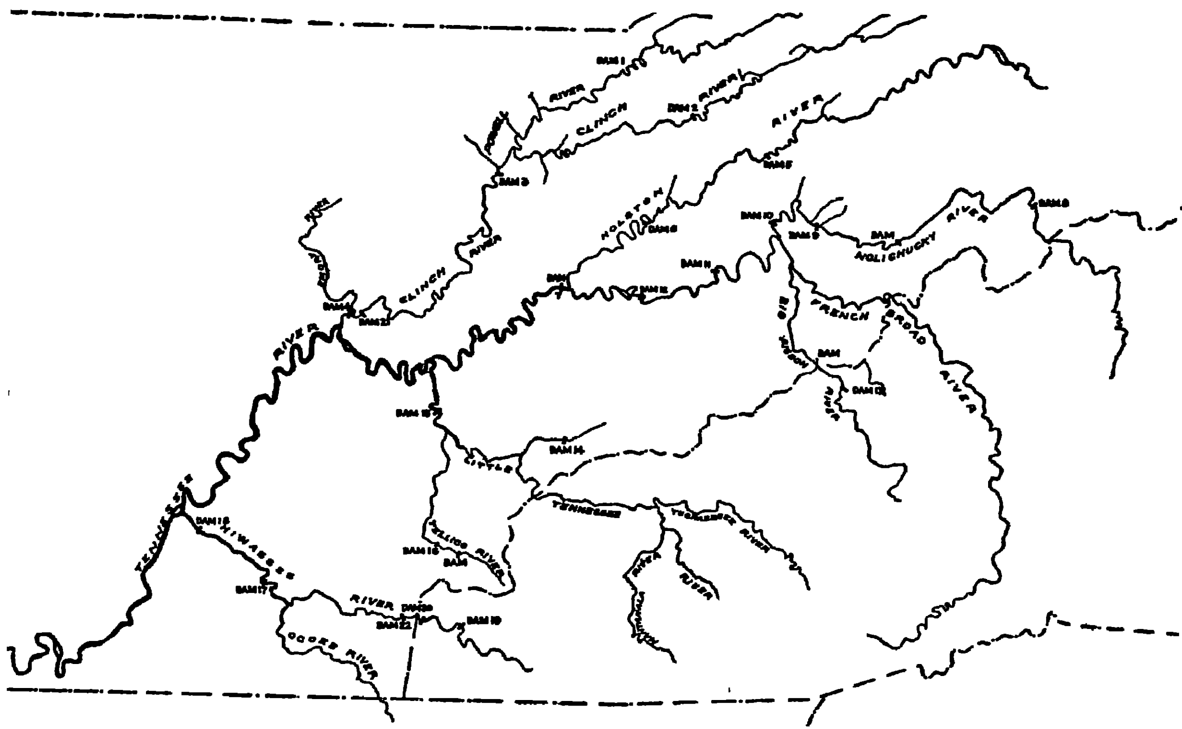
[2] *New York Times*, December 13, 1925.

Florence—the power section of the river—is 392 miles. The total drainage area is 40,750 square miles.

The water power streams of Tennessee are practically all tributary to the Tennessee River. They are, beginning at the north, as follows: the Powell, the Clinch, the Holston, the Watanga, the French Broad, which, by its confluence with the Holston, forms the Tennessee River. On the south are the Little Tennessee River with its tributaries, the Hiwassee and the Ocoee. Practically all of the potential water power sites, as represented by these drainage basins, lie in the eastern part of the state. The lower reaches of the Tennessee are devoid of tributaries having potential power sites.

THE ECONOMIC UTILIZATION OF THE TENNESSEE RIVER AND ITS TRIBUTARIES

That the most effective development of the Tennessee River system requires the formulation of a plan which will include the entire river and its tributaries has long been recognized by engineers and others who have studied this stream. Stated in its simplest terms, this means that the various proposed dams be located at those sites which will utilize the entire head of the stream, and that storage dams be built to equalize the erratic flow of the river as far as possible. The Tennessee is subject to sudden and frequent fluctuations of flow. The high water season is in the late winter and early spring and is caused mainly by heavy rainfalls. Melting snow and ice do not contribute much to this fluctuation. The practical result of the present unregulated flow of the stream is seen in the power situation at Muscle Shoals. Although the continuous power available at Wilson Dam is only 100,000 horsepower, the power obtainable during seasons of high water warrants the installation of a wheel capacity of 840,000 horsepower. Since primary, or continuous, power is far more valuable than secondary, or part-time, power, the economic value of equalizing the flow is obvious.



J. A. Switzer, *The Larger Undeveloped Water Powers of Tennessee*, Bulletin 20, 1918, Department of Education, Division of Geology.

Figure 17: Drainage basin of the upper Tennessee River with location of dams proposed by Switzer.

STORAGE DAMS

The United States Engineer Office of the War Department has been engaged in a survey of the Tennessee River and its tributaries under authorization of the river and harbor acts of September 22, 1922, and March 3, 1925. This survey is still far from completion, but a partial report has been issued to cover the work done. The recommendations of the engineer officer call for three storage dams, one just below the junction of the Clinch and the Powell rivers, and one further upstream on each of these rivers. These will have a combined available storage capacity of between 700,000 and 800,000 acre-feet, as well as a power capacity of about 120,000 horsepower.[3] With these three reservoirs operating in conjunction, there is much greater assurance that excess water can be held over for several months to the period of drought. In some measure it should even be possible to hold waters from a wet year or a period of years into a dry year or period of years. The beneficial effects of these two upper reservoirs should be felt at all the power dams now installed or proposed down to Wilson Dam, provided the plants are operated with due regard to the possibilities and limitations of this stored water. As a matter of fact, it is estimated that the primary power output at Wilson Dam could be more than doubled.

POWER DAMS

The number of power dams which can be installed in the rivers of the Upper Tennessee basin is as yet undetermined in view of the fact that many of the tributaries have not been covered by surveys. Switzer[4] places the estimate at 20 dams aggregating 720,000 horsepower without storage.[5]

[3] *Tennessee River and Tributaries, North Carolina, Tennessee, Alabama, and Kentucky,* Doc 463, House of Representatives, 69th Cong, First Session, June 26, 1926

[4] J A. Switzer, *The Larger Undeveloped Water Powers of Tennessee,* Bulletin 20, Tennessee Geological Survey, 1918.

[5] *Ibid*, p. 34.

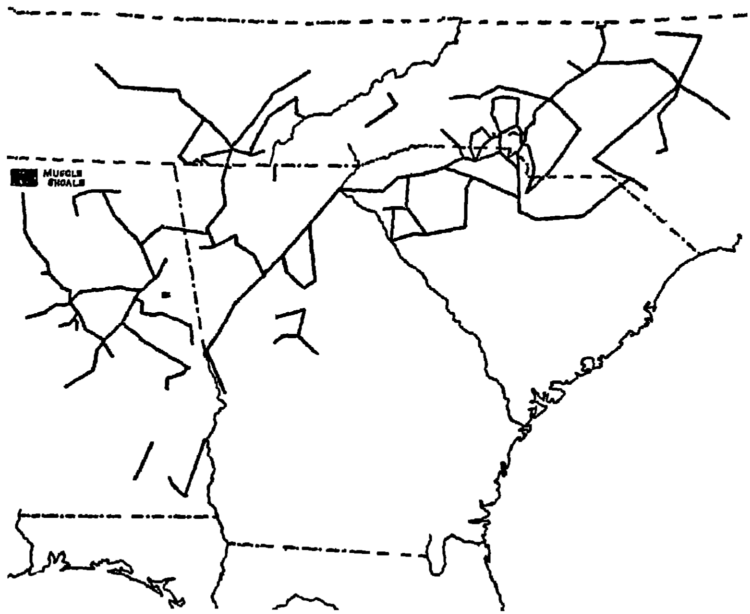


Figure 18· Southeastern power lines

This figure is based on reconnaissance surveys. Since this report was made, a more detailed survey of these sites has been undertaken by the Engineer Corps of the United States Army. This survey is not yet completed, but a preliminary report has been issued covering power estimates and costs on 13 dams. These estimates are very general and are considered to be conservative. Cost estimates are omitted where studies have progressed only so far as to show that these sites are worthy of further studies. Table 14 is an estimate covering surveys up to April 15, 1926. No estimate as yet has been made of the French Broad and the Holston rivers and their tributaries or of the smaller streams. All figures for installation and cost are subject to further revision.

TABLE 14

INSTALLATIONS ON TENNESSEE RIVER PROPOSED BY ENGINEER CORPS*

Site	Installed H p.	Cost
Interstate	260,000	$25,000,000
No. 3, Muscle Shoals	165,000	32,000,000
Guntersville	160,000	15,000,000
Sherman	45,000	6,000,000
Soddy	150,000	13,000,000
White Creek	150,000	13,000,000
Marble Bluff	70,000	9,000,000
Coulter Shoals	75,000	10,000,000
Kingston	50,000	6,000,000
Melton Hill	60,000	8,000,000
Clinton	15,000	2,000,000
Cove Creek	200,000	20,000,000
War Ridge	80,000	
Cumberland Gap	40,000	
Hiwassee River sites	350,000	
Little Tennessee sites (Aluminum Co.)	390,000	.
Big Pigeon sites	160,000	..

*Tennessee River and its Tributaries, North Carolina, Tennessee Alabama, and Kentucky, Doc. No 463, House of Representatives, 69th Congress, First Session, June 26, 1926, p 15.

ESTIMATED OUTPUT OF POWER DAMS

Upon the meager data furnished by Table 14 it would be unwise to attempt an accurate estimate of the power output. Moreover, further detailed surveys may show that some of the sites cannot be developed at a cost which will enable them to compete with steam-generated power. However, with these precautions in view, a few calculations will be made to give some idea of the importance of this power and its relation to the market demand. If we assume that the continuous power available is equal to 50% of the installed capacity and that this is operated at a 60% load factor, the output derived from the dams listed in Table 14 would be between 4 and 5 billion kilowatt hours per year. This possible output is more than 50% above the present combined central station output of the states of Alabama, Mississippi, Tennessee, and Kentucky. The production of these states for the past seven years is shown in Table 15.

TABLE 15

KILOWATT HOUR OUTPUT OF THE STATES OF ALABAMA, MISSISSIPPI, TENNESSEE, AND KENTUCKY*

Year	Kilowatt Hour Output (millions)	Percentage Increase
1921	1,311	..
1922	1,552	19
1923	1,890	22
1924	2,064	9
1925	2,538	22
1926	3,050	20
1927	3,511	15

* *Electrical World*, Vol. 91, No. 1, January 7, 1928, p. 20

MARKET FOR THE POWER

The estimated power output of these dams listed in Table 14 is sufficient to provide for the expanding market for several years to come. The rate of growth in the years 1921 to 1927 indicates, however, that initial development of the more feasible sites cannot be long delayed. Moreover, the promise of industrial growth in eastern Tennessee and northern Alabama warrants the belief that ultimately all the available power in the Tennessee River and its tributaries will be required.

In view of this fact, public economy dictates that the continued survey of the river system be provided for by ample funds, and that a comprehensive plan be laid down in anticipation of the needed power. Not only should such a plan cover those parts of the drainage system which are now under the survey of the Corps of Engineers of the War Department, but it should also be extended to cover the unsurveyed tributaries of the Tennessee River, especially that of the Little Tennessee, the French Broad, and the Little Pigeon, where large potentialities are known to exist.

This preliminary survey could be limited to a determination for each site whether a development there for power or

power and navigation is physically feasible and economically justifiable at the prevailing rates for power.

COST OF POWER

The cost of power per kilowatt hour cannot be estimated with the incomplete data at hand, but judging from the cost of power at Muscle Shoals and the cost of steam power produced under the best conditions, it is probable that hydroelectric energy could be produced in this drainage basin more cheaply than steam power.

THE WATER POWERS OF THE PIEDMONT

The water power situation in the Piedmont section of the Carolinas and Georgia is, in its economic aspects, very similar to that of the Tennessee River basin. The streams bear the same characteristics of variableness as does the Tennessee, but are smaller and have steeper gradients.

The potential water power of these states is estimated at about 1,500,000 horsepower, practically all of which is in the Piedmont and mountain section. The principal watersheds are the Savannah, the Ogeechee, the Altahama, Tallulah and Tugalo, Catawba, and Yadkin. The principal developments are on the Tallulah and Tugalo rivers in Georgia and the Catawba in North Carolina.

DEVELOPMENTS ON THE TALLULAH AND TUGALO RIVERS

The rapid industrial and commercial growth of Georgia has necessitated considerable extension of the power equipment of the Georgia Railway and Power Company on the Tallulah and Tugalo rivers. At the present time the total installed rating of the plants on these rivers is 181,000 kilowatts, with an average annual output of 531,000,000 kilowatt hours. These rivers are now utilized over a distance of 36 miles, with a total fall of 1,199 feet.[6]

[6] *Electrical World*, Vol. 87, No 15, April 10, 1926, p. 755.

THE CATAWBA RIVER

The heart of the hydroelectric development of the Piedmont of the Carolinas is the Catawba River. This remarkable stream has an available drop of 1,058 feet from the pool at Bridgewater to the tailrace at Wateree, a distance of 300 miles. The present installations use 634 feet of fall and develop a total of 383,150 kilovolt amperes when running at full capacity.[7]

The remarkable feature of the development of this stream is the use of dams and pools to change the river from a 24-hour flow period to a 15- or 18-hour flow period. This is done by adding to the storage in the reservoirs during nights and week-ends when the load is light. The Bridgewater reservoir at the head of the system is the controlling factor in the operation of the power plants. This reservoir is scheduled to be filled by September 1 each year and is then pulled down until by January 1 it is practically empty. The intermediate storage reservoirs are designed to conserve all the water behind the dams at such times as the power plants are not in operation and yet to use the water power the maximum number of hours. The pools give opportunity for storing the normal river flow in such a way as to utilize it when the full load is on the system.

THE POWER MARKET

The growth of the power market will, in the near future, require considerable installation of power equipment. That these additional needs will be met entirely by an increase in installed water power is doubtful. A large amount of undeveloped power still exists, but, with the exception of the Tugalo, the Tallulah, and the Catawba rivers, storage is difficult and the cost of development per unit horsepower is frequently high. The Piedmont section must depend for a considerable portion of its power needs upon steam-gen-

[7] *Ibid*, Vol. 83, No. 24, June 14, 1924, p 1235.

erated electricity. The economic cooperation of these two sources of power will probably resolve itself into the use of much of the water power installations for peak load purposes.

THE POWER COMPANIES IN THE SOUTHEASTERN INTER-CONNECTED POWER SYSTEM

The distribution of power in the southeastern states owes much of its effectiveness to the system of interconnections between transmission systems. A power shortage in one district can thus be easily remedied by drawing upon the power plants of neighboring systems. Such a shortage of power did occur in North Carolina in 1921 and was met by relaying surplus power from Alabama by way of the Georgia systems.

It is to be understood that this system exists, not as an organized operation, but as a group of high-voltage transmission lines and generating plants. They were begun as small units which were rapidly extended until the distributing lines nearly touched each other at various points, so that their actual interconnection required only the construction of connecting lines of comparatively short lengths.

The southeastern power system is at the present time composed of the transmission lines and stations of the following companies:

Southern Power Company, of North and South Carolina
Carolina Power and Light Company, of North Carolina
Georgia Railway and Power Company, Georgia
Central Georgia Power Company, Georgia
Columbus Power Company, Georgia
Alabama Power Company, Alabama
Tennessee Power Company, Tennessee

This system has a total length of over 3,000 miles of high-voltage lines. The area that is now served by the system is approximately 120,000 square miles. Upon completion of the plants under construction and immediately pro-

posed, the systems of the Carolinas will have a total generating capacity of 606,550 kva., the Alabama system, 571,800 kva., the Georgia system, 406,400 kva., and the Tennessee system, 196,405 kva., making a total of 1,785,155 kva., with a total annual output of about 5,000,000,000 kilowatt hours.

VI

THE COLORADO RIVER

The twofold function of the Colorado River. Problems of the Colorado River region. Flood control. Irrigation. Domestic water supply. Water power Résumé Potential power in the Colorado River Plan of development between west boundary of Grand Canyon National Park and Parker, Arizona. The Boulder Canyon project The possible market for the lower Colorado River power. Conclusion.

THE Colorado River is perhaps the most remarkable river in North America, considering its potential usefulness. It combines in the proper order the adaptability for use of a large quantity of its water for irrigation purposes, great concentrations of fall, reservoir sites for the control and regulation of flow, suitable power sites, and adjacent to it are large areas of land upon which its waters may be turned.

The drainage basin of the Colorado covers 244,000 square miles situated in 7 states.

The tributaries of the Colorado rise in the mountains of Wyoming, Colorado, and Utah, where the snowfall is heavy. The physical features of the stream cause it to fall into three natural divisions: The headwaters basin above the mouth of the San Juan; the canyon region from the mouth of the San Juan to the mouth of the Virgin River, where the Colorado turns almost due west; and the valley region from the mouth of Black Canyon southward to the Gulf of California. The most important power sites are between the mouth of the San Juan and the mouth of Black Canyon, the total fall between the two points being about 2,500 feet.

THE TWOFOLD FUNCTION OF THE COLORADO RIVER

The Colorado River is probably the only western stream upon which power and irrigation projects can be developed

to the fullest extent without serious conflict. The canyon section of the river offers the second largest concentration of power sites in the United States and the third largest on the continent. It is exceeded only by the St. Lawrence and the Columbia rivers in this respect. By building reservoirs at or near the upper end of the stretch of great fall, whereby the erratic natural flow of the river may be converted to a discharge which will be nearly uniform, the value of the power sites may be greatly increased.

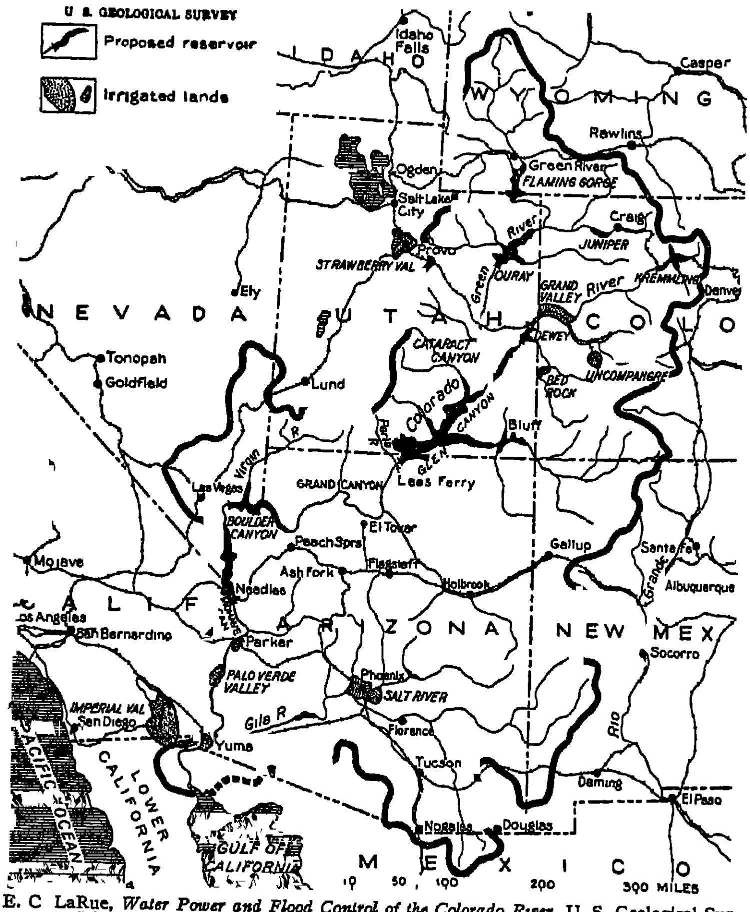
Below Black Canyon and not interfering with power development in the canyon section, the river flows through great areas of potentially fertile land that may be made productive by irrigation. The distribution of water for irrigation needs differs from that for the power needs so that the reservoir system in the upper reaches of the river designed for power improvement are not exactly adapted to the needs of the irrigable section. However, natural conditions below Black Canyon favor the building of a large storage reservoir to re-regulate the flow in accordance with the seasonal needs of growing crops.

PROBLEMS OF THE COLORADO RIVER REGION

The problems facing the areas comprising and adjacent to the Colorado River may be grouped under flood control, supply of irrigation water, domestic water supply, and power. Probably the most urgent of these problems is that of flood control.

FLOOD CONTROL

Ever since their development the irrigation projects in the lower Colorado River basin have been seriously menaced by floods in the Colorado and Gila rivers, and amelioration of this condition is the most pressing need for construction on the river at this time. The river in this section carries great quantities of silt and has built up its bed above the adjoining country. It is prevented from entering the irrigated areas by levees, built and maintained, at large expense, by the irrigation projects. The



E. C LaRue, *Water Power and Flood Control of the Colorado River*, U S. Geological Survey, Water Supply Paper 556, Plate 1.

Figure 19 · Map of the Colorado River drainage basin.

floods from the Gila are due to winter rains, while those in the Colorado are due to melting snows in the summer, when the Gila is practically dry. The Gila floods have reached a flow as high as 240,000 cubic feet per second, which is probably above the maximum reached by the Colorado. The Gila floods are of short duration, however, while the Colorado floods last about three months The Gila floods are as apt to overtop the levees as the Colorado floods, but the cost of maintaining a flood channel for

them is very much less and the damage in case of a break is also very much less. So long as the Gila remains uncontrolled, the levees will have to be maintained to their present dimensions.

The Colorado River floods, aside from the threat of tremendous damage in case of breaking into irrigated areas, cause heavy yearly expenditures for the maintenance of the levee system. During the period of high water, with varying flow, the Colorado shifts its channel between the levees, and each shift is apt to produce attacks upon the levees at several new points. If the channel could be stabilized between the levees the maintenance cost would be much reduced. The stability of the channel is much more affected by the great range of seasonal variations in the flow than it is by the size of the maximum flow. If the flow were uniform, the channel would adjust itself to a velocity that would not move much material, and the cost of maintenance would be small.

The instability of the present channel is undoubtedly considerably aggravated by the diversions for irrigation during the low water period and also by the practice of taking from the water diverted all the sediment possible and returning it to the river channel to be handled by the reduced flow. The ideal condition, so far as flood protection is concerned, would be to regulate the flow so that it could always be uniform below the irrigation diversions. On account of cost and interference with other uses of the water such an ideal will never be realized, but the nearer it is approached the less will be the cost of protecting the lower basin. The problem is so complicated that it will not be possible to determine the exact limit of flood flow that will guarantee relief from flood danger. The Reclamation Service has concluded that if the flood flow be limited to a maximum of 50,000 cubic feet per second sufficient relief will be afforded.

The lower the maximum flow, the nearer the annual flow will be equated and the greater will be the flood benefit; but no outstanding reasón is given for adopting 50,000 cubic feet per second as a maximum, and in view of the fact that the channel will have to carry from time to time as much as 250,000 cubic feet per second so long as the Gila remains uncontrolled, it is generally believed that an initial reduction of the maximum flood flow of the Colorado to 75,000 cubic feet per second and a building up of the minimum flow to 10,000 cubic feet per second can be considered as giving material relief for a first step, if additional

relief can be looked forward to in the not too distant future as other projects on the river provide more storage.[1]

IRRIGATION

The irrigation problem is mainly to insure an adequate supply of water for the Imperial Valley, and for possible future demands in adjacent sections of Arizona and California. Under the present arrangement, all the irrigation water for this valley is carried through an old channel, known as the Alamo channel, some 60 miles through Mexico back into the United States. In order to carry the waters into Mexico and deliver it back into the United States for the use of American citizens it was necessary to organize a Mexican corporation for the purpose of receiving the water at the international line, operating the canal system in Mexico and then delivering the water to the United States, as the Mexican Government would not permit this to be done by a corporation or political agency of the United States.

The Mexican company obtained a contract, or concession, from the Government of Mexico whereby it was granted the right to receive the water and deliver it back into the United States, provided that the lands in Mexico receive from the canal all the water required for use in Mexico, not exceeding one-half of the amount passing through the canal.

The operation of the canal under this concession has not been satisfactory and may become dangerous to American interests in the future. Development has constantly proceeded in Mexico to such an extent that in 1925, 217,000 acres were furnished water from the main canal. Moreover, Mexican users pay only 85 cents an acre-foot, while the cost to American users is over $2. In other words, the high cost on the American side places domestic producers at a distinct disadvantage in the market. This rapid development is more clearly understood by reference to Table

[1] *Second Annual Report of the Federal Power Commission*, 1922, pp. 179, 180.

TABLE 16

ACREAGE UNDER IRRIGATION IN IMPERIAL IRRIGATION DISTRICT*

Year	Acres	Year	Acres
1908	6,935	1917	77,500
1909	9,051	1918	118,530
1910	14,920	1919	136,580
1911	14,953	1920	190,000
1912	21,599	1921	120,000
1913	33,761	1922	150,000
1914	39,600	1923	180,000
1915	41,000	1924	185,022
1916	67,500	1925	217,000

* *Boulder Canyon Reclamation Project*, Senate Report 654, 69th Congress, First Session, April 19, 1926, p. 17.

16 prepared by the general superintendent of the Imperial Irrigation District.

There are more than 800,000 acres of land in Mexico susceptible of irrigation by gravity from this system. With Mexico constantly extending its use, the development in the United States is now arrested, and it is only a matter of time until lands in the United States now irrigated will of necessity be abandoned so that Mexico can be supplied with its half of the water.

This situation is described in a report by the Secretary of the Interior to the Senate Committee on Irrigation and Reclamation:

> The canal now supplies water for the irrigation of over 400,000 acres in California, and irrigators in Mexico at present require water for the irrigation of 200,000 acres. But Mexican irrigators are entitled, under this concession, to double the volume they are now using, or for enough to irrigate as many acres as are now irrigated in California. That is more water than the unregulated flow of the river will now supply. As the Mexican irrigators are on the upper end of the canal, the pinch of scarcity, when it has come in the past, or when it may come in the future, falls first on irrigators in the United States, which country supplies the water, all the construction costs, and all the money advanced for operation.[2]

[2] *Boulder Canyon Reclamation Project*, Senate Report 654, 69th Congress, First Session, April 19, 1926, p. 18.

To overcome this situation, the construction of an all-American canal is being urged.

DOMESTIC WATER SUPPLY

The third problem is that of domestic water supply for the cities of the coastal belt of southern California, with a population of nearly 2,000,000 people. The water supply in this locality is affected by cycles of wet and dry periods, periods of 10 to 12 years in which the average rainfall and stream flow are below normal, followed by periods of the same duration in which they rise above normal. Because of increase of population, even average water conditions will leave a shortage of supply in a few years. To meet this situation, the cities of that region have been investigating possible sources of additional water supply. These investigations have shown that about 1,500 second-feet of water for domestic purposes only will be required for these communities, and that the only possible source is the Colorado River.

WATER POWER

Finally, and probably least urgent of the four problems, is that of power supply. At the present time, the power requirements of California can be supplied from developments on the rivers of the Sierra Nevada mountains and the valley of California. This situation, however, is not expected to continue indefinitely. In fact, if projects now contemplated are completed, the largest and most cheaply developed water power resources of California will have been utilized by 1935, and any further increases in power demand must come from the Colorado River sites.

Superimposed upon the four specific problems discussed above is the question of river administration. The river is an interstate and international stream. Hence any plan for the utilization of the waters of this stream for irrigation, power, or any other purposes, cannot proceed except by

mutual agreement of the states or countries involved.[8] Such an agreement between the states, known as the Colorado River compact, has been formed, and had its inception in the desire of the upper basin states to secure and reserve for themselves sufficient water from that stream to care for their future development. The existing law of appropriation, giving priority of water rights without regard to state lines, did not give them that security. A seven-state agreement was signed by representatives of the interested states at Santa Fe, New Mexico, on November 24, 1922. All the states except Arizona promptly ratified this compact. In 1925 a six-state ratification of this compact was suggested, and the four upper basin states and the state of Nevada in the lower basin made such a ratification. California consented to the six-state ratification but made its ratification contingent upon large storage being authorized.

RÉSUMÉ

The utilization of the Colorado River is complicated because of its interstate character and the diversity of demands upon its water resources. No attempt will be made here to discuss these problems in detail, attention being confined to the power situation alone.

POTENTIAL POWER IN THE COLORADO RIVER

Studies made by the engineers of the Geological Survey indicate that 13 projects will be necessary for complete development of the power resources of the Colorado River between the mouth of the Green River, Utah, and Parker, Arizona. The elevation ranges from 4,040 feet at the highest to 358 feet at the end of the power section. In calculating the water power value of the several sites, the problem of flood control and the use of water for irrigation have received first consideration. The power capacity is given for present and for future conditions when the flow

[8] California, Arizona, New Mexico, Colorado, Nevada, Utah, and Wyoming.

will have been depleted by the development of irrigation.

A plan for development of the river suggested by the engineers of the Geological Survey would call for the construction of power dams at twelve locations in addition to dams for storage and irrigation control. The power value of the river, as determined from water supply conditions of 1922, with storage at the site near Lee's Ferry, is estimated at 4,345,000 continuous horsepower. If the plants operated at a load factor of 60%, the total installed capacity would be 7,242,000 horsepower. Without storage the total power available would be 1,758,000 horsepower 90% of the time and 2,747,000 horsepower 50% of the time. With maximum use of water in the upper basin the total available continuous power would be about 3,419,000 horsepower. If the plants operated under a 60% load factor, the total installed plant capacity would be 5,743,000 horsepower.[4]

PLAN OF DEVELOPMENT BETWEEN WEST BOUNDARY OF GRAND CANYON NATIONAL PARK AND PARKER, ARIZONA

The rapidly increasing population in southern California, together with a severe drought in 1924, has resulted in an active discussion of the early development of the lower section of the river not only to supply power needs but also to furnish an adequate water supply for domestic and municipal purposes. The most effective development of the stream so that its use for domestic consumption, irrigation, and water power may be utilized to the fullest extent demands a comprehensive plan which will take into account the entire river. The hitherto haphazard development of many water power sites on American rivers has resulted in a condition whereby the full utilization of a river is prevented except at prohibitive costs. Such mistakes should be avoided in the case of the Colorado. In the lower part of the river any part of development must conform to the utilization of

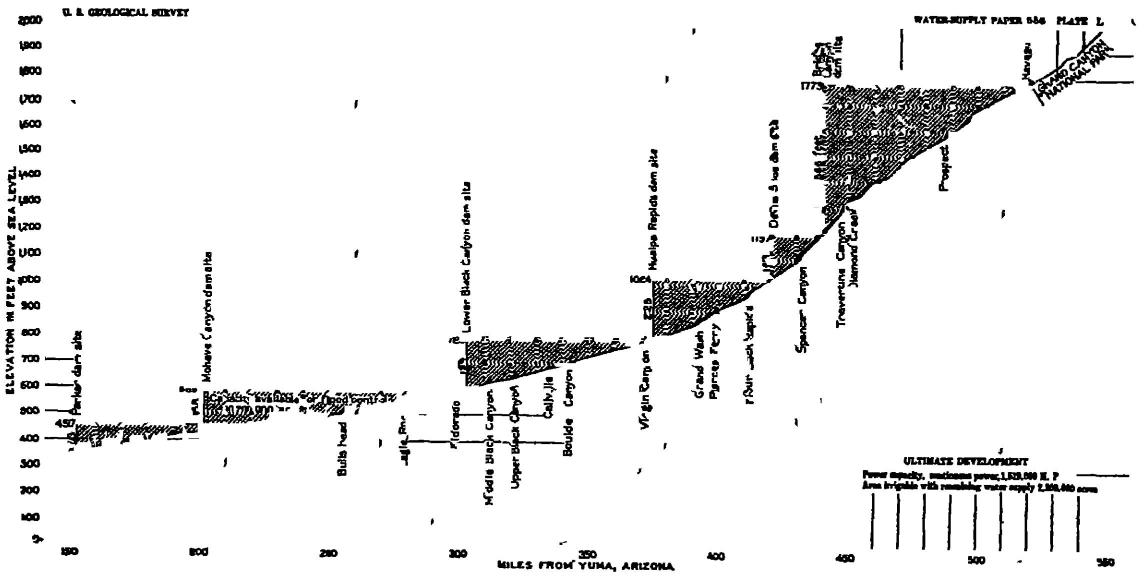
[4] E. C LaRue, *Water Power and Flood Control of Colorado River Below Green River, Utah,* Water Supply Paper 556, U. S Geological Survey, 1925, p. 46.

the water for the three purposes mentioned—domestic consumption, irrigation, power—named in the order of importance.

An intensive study of the lower Colorado has been made and 23 dam sites have been located and surveyed. In this section of the river the fall is 1,425 feet. Several plans have been suggested for the development of the stream, all of which fall into one of two classes. In the one class are those plans which contemplate building a high dam at or near Boulder Canyon for the fourfold purpose of flood control, storage for irrigation, storage of silt, and the development of power. In the second group the plans call for regulation of flow by storage in a series of dams above Lee's Ferry with one dam in Mohave Canyon to furnish preliminary storage for flood control and irrigation. The details of a plan under the second group are shown in Figure 20.

The plan suggested by the writer is based on the theory that a more efficient use of the available water supply may be had by separating the problem of flood control and storage for irrigation from the power problem. In his plan 10,200,000 acre-feet of storage capacity for flood control and irrigation is to be provided at Mohave Canyon. A diversion dam at Parker is recommended so that the waters of Colorado River may be used for irrigation of lands situated in the United States. For the stretch above the Mohave Canyon reservoir the plan calls for the construction of dams that may be operated to obtain a maximum development of power. These dams step up the river to the west boundary of the Grand Canyon National Park, so as to permit full use of the fall in the river for power. Four power dams are suggested—at lower Black Canyon, Hualpai Rapids, Devils Slide, and Bridge Canyon (see profile). The ultimate power available, after allowing for losses of water by evaporation and for irrigation, is estimated at 1,519,000 horsepower.

With the water supply now available and with development accomplished as suggested by the writer, the loss of water due to evaporation would be reduced to a minimum, and a maximum of power could be developed. If the plan of development that calls for a high dam at or near Boulder Canyon were followed, the additional loss of water due to evaporation from the water surface of the reservoirs would be about 800 second-feet, and the consequent loss of power would exceed 230,000 horsepower.



E. C LaRue, *Water Power and Flood Control of the Colorado River*, U S. Geological Survey, Water Supply Paper 556, 1925, Plate 50.

Figure 20 Plan of development of the Colorado River between Grand Canyon National Park and Parker, Arizona.

The loss of water at present is not a serious matter, for a great surplus passes into the Gulf of California each year. Before many years pass, however, the demand for water will be greater than the available supply. It would therefore be unwise to carry out a construction plan that would forever prevent the full use of the water resources of the river. The real test of the soundness of the several plans suggested lies in a comparison on the basis of ultimate development of the water resources of the region. A thorough analysis of the plans that call for a high dam at or near Boulder shows that with complete development in the upper basin and with the lower river developed as suggested by the writer, 103,000 acres more land could be irrigated and an additional 251,000 horsepower could be developed.

The Mohave Canyon storage reservoir, operated solely in the interests of flood control and irrigation, would provide the most satisfactory solution of this phase of the problem, as it would be 120 miles nearer the lands that would be benefited by such storage than the Boulder Canyon site.

It would be possible to provide 2,000,000 acre-feet of available storage capacity at the Parker dam site, but such a plan would seriously interfere with the full use of water for irrigation. Under such a plan it would be necessary to pump the water an additional 33 feet to reclaim by irrigation some 700,000 acres of land below Parker. With the Mohave Canyon reservoir in operation, it would not be necessary to provide available storage capacity at the Parker dam site.

The writer suggests that his plan should be given serious consideration for the following reasons:

1. It provides the most effective means of flood control and storage for irrigation.
2. It solves the problem of silt storage for several generations.
3. It provides a maximum use of water for both irrigation and power development.
4. It calls for a minimum departure from present engineering practice in the construction of dams.[5]

THE BOULDER CANYON PROJECT

The director of the Reclamation Service on February 28, 1922, through the Secretary of the Interior, recommended

[5] E. C. LaRue, *op. cit.*, pp. 70-72.

to Congress the construction of a dam at Boulder Canyon. Subsequently, a bill was introduced in the House of Representatives by Mr. Swing and in the Senate by Mr. Johnson providing legislation to carry out this proposal. This is known as the Swing-Johnson bill. This bill proposed the construction of a dam about 600 feet high, which would create a reservoir of 26,000,000 acre-feet and provide upwards of 600,000 horsepower.

The estimated cost of the entire project is given in Table 17.[6]

TABLE 17

COST OF BOULDER CANYON PROJECT

CAPITAL INVESTMENT	
Estimated cost for—	
26,000,000 acre-foot reservoir	$ 41,500,000
1,000,000 horsepower development	31,500,000
The all-American canal	31,000,000
Interest during construction on above five years at 4%	21,000,000
Total	$125,000,000
ANNUAL OPERATION	
Estimated gross revenues from—	
Sale 3,600,000,000 kilowatt hours of power at three-tenths cent	$ 10,800,000
Storage and delivery of water for irrigation and domestic purposes	1,500,000
Total	$ 12,300,000
Estimated fixed annual charges for—	
Operation and maintenance, storage, and power	$ 700,000
Operation and maintenance, all-American canal	500,000
Interest on $125,000,000 at 4%	5,000,000
Total	$ 6,200,000

The estimated annual surplus, $6,100,000, is thought to be sufficient to repay the entire cost in 25 years.

The chief objection to the Boulder Canyon site is that there will be a much larger loss through evaporation than under LaRue's proposal. However, this is offset by the fact

[6] *Boulder Canyon Reclamation Project*, Senate Report 654, 69th Congress, First Session, April 19, 1926, p 24.

that the Boulder site is considerably nearer the available power market—an important element from a financial standpoint. Secretary Hoover stated that "there are theoretical engineering reasons why flood control and storage works should be erected farther up the river and why storage works should be erected farther down the river; and I have not any doubt that given another century of development on the river all these things will be done. The problem that we have to consider, however, is what will serve the next generation in the most economical manner, and we must take capital expenditure and power markets into consideration in determining this. I can conceive the development of probably 15 different dams on the Colorado River, the securing of 6,000,000 or 7,000,000 horsepower; but the only place where there is an economic market for power today, at least of any consequence, is in southern California, the economical distance for the most of such dams being too remote for that market. No doubt markets will grow in time so as to warrant the construction of dams all up and down the river. We have to consider here the problem of financing; that in the erection of a dam—or of any works, for that matter—we must make such recovery as we can on the cost, and therefore we must find an immediate market for power. For that reason it seems to me that logic drives us as near to the power market as possible, and that it therefore takes us down into the lower canyon."[7]

An attempt was made in the Senate to pass the Swing-Johnson bill in the closing days of the 70th Congress, February, 1927, but it failed to come to a vote.

THE POSSIBLE MARKET FOR THE LOWER COLORADO POWER

The market possibilities of the Colorado basin make it feasible to develop at the present time only the water power sites of the lower Colorado in northwestern Arizona. Applications for sites on the upper Colorado and its principal

[7] Hearings on Sen. Res. 320, 68th Congress, Second Session, p 601.

tributaries are being filed, but the power, if developed, will supply the eastern Utah and western Colorado market and will in no way compete with power developed in the Lower Colorado.

There is at present no market for hydroelectric power potentially developable at Glen Canyon Reservation sites and the Marble Canyon Reservation sites located just above the Grand Canyon National Park. The only sites on the river that can find a market for electrical energy, if developed, are those between Black Canyon and Diamond Creek. The principal market is in the state of California, with smaller markets in Arizona and Nevada. In the case of Nevada no general market can be expected. It is improbable that a load of more than 5,000 kilowatts can be expected, which is insignificant in as large an installation as would be required on the Colorado.

The market in Arizona is expected to require approximately 260,000 kilowatts (346,000 horsepower) installed capacity by 1945.[8]

California, then, constitutes the largest possible market. The power requirements by 1945 are estimated at about 5,000,000 kilowatts installed capacity.[9] In order to utilize the entire output of a proposed hydroelectric plant on the Colorado, it may be necessary to postpone development of some of the California rivers until all of the Colorado power has been absorbed. Since the power on the latter river will cost nearly as much as power from projects within the state which it is to replace, it cannot enter through competition. Its entry will depend upon agreement with the California companies to postpone developments now under consideration.

CONCLUSION

The utilization of the Colorado River is now confined to the problem of the proper allocation of its waters to irriga-

[8] *Second Annual Report of the Federal Power Commission,* 1922, p. 194.
[9] *Ibid.,* p. 193.

tion, power, and domestic water supply among the several states through which it flows. Equally important are the questions of policy of administration, whether it shall be developed and operated by the government or under private initiative. The interstate character of the stream and the physical necessity of constructing plants of large installed capacity—larger than any erected thus far—may, in itself, mean that the development must be undertaken by the Federal Government.

Moreover, the disposal of the power is not merely a question of supplying an expanding market. This could, no doubt, be supplied for the near future by the California water powers. There must be an agreement that these latter water powers will not be developed until the hydroelectric energy made available by the initial developments on the Colorado River is first absorbed.

VII

WATER POWERS OF THE PACIFIC DRAINAGE

The isolation of the West Coast The peculiar power situation on the West Coast. Physiographic and hydrographic features of the Pacific drainage The drainage basins of the West Coast The distribution of power resources The situation in California. Characteristics of California rivers Ultimate water power resources Market possibilities The more important power developments in California The Sacramento and its tributaries Pit River; Feather River; Middle Fork; Yuba River; American River. The San Joaquin River and its tributaries, Mokelumne River, Tuolumne River, Kings River. Kern River developments. Owens Valley region Résumé The relation of steam to hydro in California The Pacific Northwest The Columbia River drainage basin, power possibilities The Snake River basin, undeveloped water power The Deschutes River; market for Deschutes River power. Willamette River. Other tributaries of the Columbia. The market possibilities. Potential markets

THE wide expanse of arid and semiarid lands, beginning approximately on the 100th meridian and extending to the crest of the Sierra Nevada mountains, has served to hamper the free movement of goods between the East and the West to the extent that, in spite of many handicaps industrialism is entering the Pacific Coast states. If these states are far removed from the manufacturing centers of the East, their isolation is recompensed, in part, by the variety of their resources. If the raw materials and power resources are not as abundant as in the East, nevertheless they are of sufficient extent to make possible a considerable agricultural and industrial development.

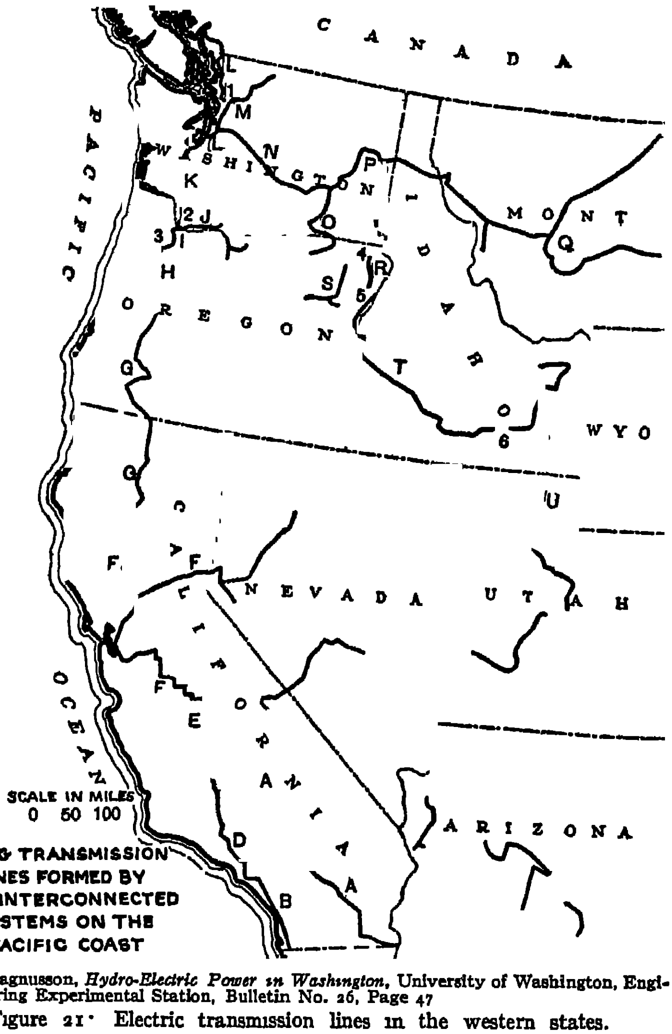
The two principal activities of the West Coast are agriculture and forestry, and the industries dependent upon them such as meat packing, tanning, paper making, flour milling, and canning. Although there are considerable iron deposits, the usefulness of this mineral for industrial development is impaired by the fact that coal for smelting the ores is limited.

THE PECULIAR POWER SITUATION ON THE WEST COAST

The outstanding feature of the power resources of the Pacific Coast is the abundance of water power and the absence of coal. Petroleum is the most important source of energy at the present time, but the ultimate decline of the fields is expected. Large deposits of oil shale exist, but are as yet unutilized. In the not far distant future these states will place their main reliance upon hydroelectric energy. Under the conditions existing in this region this form of power has both advantages and sharp limitations. Once developed, hydroelectric energy is practically permanent, and, in spite of the large dams and long transmission lines required, this source of power is probably as cheap as that obtainable from imported coal. It means, also, that industrial development is limited by the total available water power. As soon as the potential resources have been developed, further industrial expansion will be sharply curtailed unless fuel can be imported at a reasonable cost. Moreover, the dependence of an industry in an isolated industrial region upon fuel imported by way of the Panama Canal is an extremely hazardous one.

PHYSIOGRAPHIC AND HYDROGRAPHIC FEATURES OF THE PACIFIC DRAINAGE

The topography and climate of the coastal states is well adapted to the production of a large amount of potential water power. In general, the north-south trend of the mountain ranges causes the moisture-laden winds from the Pacific Ocean to drop their moisture on the western slope of the mountains, thereby furnishing an abundance of water flowing down from high altitudes, the two requisites for abundant water powers. This condition is particularly well marked in the Sierra Nevada mountains of California and the Cascade ranges of Oregon, Washington, and British Columbia. The northern Rockies in Idaho and Montana



C E. Magnusson, *Hydro-Electric Power in Washington*, University of Washington, Engineering Experimental Station, Bulletin No. 26, Page 47

Figure 21· Electric transmission lines in the western states.

cause the precipitation of rains which feed the Columbia River and its tributaries, the Snake and the Grand Fork. The river channels are marked with frequent gorges or narrows offering many favorable sites for the location of dams.

THE DRAINAGE BASINS OF THE WEST COAST

The most important drainages of the 1,200,000 square miles of the United States and Canada lying west of the Rocky Mountains are:

1. The Columbia River drainage, 259,000 square miles, of which 34,700 square miles is in Canada.
2. The Colorado River drainage, 244,000 square miles.
3. The Coast drainages comprising, in order, southward:
   a) The coastal streams of British Columbia from Portland canal on the Alaskan boundary to Puget Sound.
   b) Vancouver Island.
   c) The area tributary to Puget Sound in the United States, 14,300 square miles.
   d) The coast areas in Washington and Oregon, and in California, north of San Francisco Bay, tributary directly to the Pacific Ocean, 44,700 square miles.
   e) The Sierra Nevada streams draining into San Francisco Bay, or into the closed basins of Tulare and Kern Lakes, the entire area in the Great Valley embracing 59,800 square miles; also Owens Lake.
   f) The coast streams emptying into the Pacific south of San Francisco are unimportant.

THE DISTRIBUTION OF POWER RESOURCES

The potential power sites of the Pacific drainages are many in number and wide in their geographical distribution. Moreover, they include about 40% of the total potential resources of the entire United States. The power demand in the western states, however, does not call for the development of all of these resources, or even a major portion of them. Interest, therefore, centers upon those sites which are capable of economic development under conditions of the present and immediate future. On the West Coast there are six market centers around which hydroelectric developments may economically proceed. These centers are, the Los Angeles district, the northern California market, Port-

land, the Puget Sound area, the eastern Washington market, and British Columbia. In these six centers dwells more than 40% of the population of the Pacific States, and the expected expansion of the manufacturing industries will tend further to increase the concentration of population in these regions.

THE SITUATION IN CALIFORNIA

The utilization of California streams for power purposes must take into account the water requirements for irrigation. The laws of California give the irrigator preference over the power user in the rights to the water. In many cases the same stream that furnishes power is used for irrigation after it reaches the valley lands. Practically all the important rivers that descend each slope of the Sierra Nevada are thus used. There is an apparent conflict between the two uses of water. Power demands a fairly uniform flow throughout the year. Irrigation demand varies between wide limits, ranging from 1% to 2% in some months to as much as 20% or 22% of the total seasonal quantity used. During two or three months of the year, there is no irrigation, and then reservoir gates are closed to store water for next year.

The solution of this problem must be found in the difference in reservoir location. Power requires that water be stored near the headwaters of rivers, in order to take advantage of as much head as possible. For irrigation, however, the reservoirs are needed near the exit of the river from the mountains, in order to obtain the greatest tributary watershed Whatever water is released from power storage reservoirs during the irrigating season is of benefit to irrigation, passing directly to the lands. Water released for power during the nonirrigating season can be retained in the irrigation reservoir for use the next season, and thus insures against failure of irrigation water for a possible future deficient flow of the stream. The irrigation reservoir becomes, in effect, a re-regulating reservoir, changing the stream from the character given it by power regulation to one serving irrigation.[1]

[1] John D. Galloway, "Hydro-Electric Developments on the Pacific Coast" *Proceedings of the American Society of Civil Engineers,* Vol 48, No. 10, December, 1922, p. 1856.

CHARACTERISTICS OF CALIFORNIA RIVERS

Those who are familiar with the flow of streams in more humid regions will be greatly impressed by the extreme variations in the flow of streams in California, not only between different years, but between different seasons in the same year. These wide variations prevail throughout the West. The stream flow is characterized by very high floods in the spring and very marked drops late in summer and early in the fall. Table 18 gives a general idea of the flow of the principal power streams for which consecutive records are available. In drawing general conclusions from this table the reader must carefully keep in view two points —first, that the records for several of the stations are incomplete, and second, that the flow of several of the streams is more or less affected by the release or the holding back of stored water.

TABLE 18

ANNUAL FLUCTUATIONS IN STREAM FLOW (CALIFORNIA RIVERS)*

Stream	Daily Minimum Flow (*second-feet*)	Daily Maximum Flow (*second-feet*)
Pit River	2,450	35,600
North Fork of the Feather River	465	9,850
Feather River	820	187,000
North Fork of Yuba River	109	11,000
Yuba River	165	111,000
American River	65	105,000
Mokelumne River	20	16,700
Tuolumne River	indeterminate	52,600
San Joaquin River	170	15,900
Kings River	130	17,100
Kern River	142	10,400

* F H Fowler, *Hydro-Electric Systems of California and Their Extensions into Oregon and Nevada*, Water Supply Paper 493, U. S. Geological Survey, 1924, pp 24, 25.

A brief study of the table discloses the unsatisfactory characteristics of these rivers for power production without storage. Sites for storage dams in the upper drainage

basins to retain the normal annual run-off are, however, economically feasible.

ULTIMATE WATER POWER RESOURCES

The rapid development of the hydroelectric industry in California naturally leads to an inquiry as to the ultimate resources developable. At the present time this can be stated only in terms of a rough estimate. A vast amount of data has been accumulated both by the engineers of the Forest Service and by the officials of the California State Water Commission, but these have not yet been analyzed sufficiently to make a detailed report. A recent estimate by the Geological Survey (April 29, 1924) places the resources of California as:

4,603,000 h.p. available 90% of the time;
6,674,000 h.p. available 50% of the time.

A mere census of total physical water power potentialities, however, is meaningless, except as a basis for measuring the extent to which possible future demands for energy can be met. The developments of the immediate future must be measured against the extent and probable future growth of the present market.

MARKET POSSIBILITIES

The future demand can be forecast to some extent from past production. In Table 19 is given the kilowatt hour output of central stations (including steam)[2] and the installed capacity of hydroelectric plants.

That the rate of increase, as shown in the table, is likely to continue in the future is doubtful. The cumulative effect of compounding at so high a rate would presuppose a rate of growth of population and industry that has never been

[2] Steam stations generated about 16% of the central station energy, but this proportion will decrease as later hydro developments are brought into operation.

TABLE 19

KILOWATT HOUR OUTPUT OF CENTRAL STATIONS AND THE INSTALLED CAPACITY OF HYDROELECTRIC PLANTS*

Year	Kilowatt Hour Output	Percentage Increase	Installed Capacity (*Horsepower*)
1921	3,982,938,000	..	1,149,099
1922	4,379,703,000	10	....
1923	5,069,314,000	16	.. . ..
1924	5,566,440,000	10	1,451,830
1925	6,215,813,000	12	1,531,480
1926	6,898,260,000	12	1,834,890
1927	7,510,000,000	9	....

**Electrical World*, Vol. 91, p. 20, January 8, 1928.

equaled over a long period of time. Fowler estimated, in 1922, that the California load at the two principal market centers, the southern coastal strip and the northern California market, would be about 19,000,000,000 kilowatt hours in 1940, requiring an installation of 2,900,000 horsepower, or an increase of about 1,100,000 over the 1926 installation.[3] In the light of present-day developments, this estimate is probably too low. In addition to the present installation of 1,800,000 horsepower, the projects now in progress, or contemplated, will add about 450,000 horsepower by 1928, bringing the total up to 2,250,000 horsepower.

At the present time the rate of increase in the consumption of electrical energy is affected somewhat by the use of California oil for power purposes. The principal users of oil in California are the railroads, the public utilities, and industrial plants. In 1924, despite the widespread development of hydroelectric power, oil still produced over 70% of the energy utilized in the state.[4] The ultimate decline of

[3] F. H. Fowler, "Water Power Potentialities of the Pacific Coast," *Proceedings of the American Society of Civil Engineers*, Vol. 49, No 5, 1923, pp. 923, 924

[4] F. H. Fowler, *Hydro-Electric Systems of California and Their Extensions into Oregon and Nevada*, U. S Geological Survey, Water Supply Paper 493, 1924, p. 854.

the oil fields, however, coupled with an increasing demand for the refined products of petroleum, will hasten the change from oil power to hydraulic power wherever this change can be accomplished.

It is obvious that only a partial substitution for oil is possible. The coastwise vessels, which are the largest users of oil, cannot, of course, be electrified, and the railroads, also large consumers of oil, are not in a financial condition to assume the costs of early electrification. Eventually, however, electrification on some of the lines will be accomplished.

Fowler estimates that 37% of the present oil consumption, principally that used by public utilities and industrial plants, could be eliminated by available water power.[5] While the present large output of oil in California continues, any immediate increases in hydroelectric installation due to changes from oil-electric to hydroelectric power will be slow in forthcoming.

It must not be inferred that developments will continue until all the potential water powers of the state are harnessed. Each new installation in the future will probably be made at a higher cost per installed horsepower inasmuch as the more desirable and cheaper sites are developed first.

This means an increasing cost per kilowatt hour which will be reflected in a less rapidly growing demand. Ultimately, a point will be reached where development of high cost sites will no longer be profitable. The utilization of California power sites is also contingent upon the policy adopted for the development of the Colorado River.

THE MORE IMPORTANT POWER DEVELOPMENTS IN CALIFORNIA

The Great Valley of California is drained by the Sacramento and San Joaquin rivers, these streams emptying into San Francisco Bay, and by several streams discharging into

[5] *Ibid.*, p. 876.

Tulare and Kern lakes basin. The total area represented by these basins is 59,500 square miles. Only those streams draining the western slope of the Sierra Nevada, and the extreme southern end of the Cascade Range, have important water power possibilities. The most important of these are the Sacramento River and its tributaries (Pit River, Feather River, Yuba River, American River), the San Joaquin and its tributaries (Mokelumne, Tuolumne, Stanislaus, Merced, Kings), and Kern River draining into Kern Lake.

DEVELOPMENTS ON THE PIT RIVER

This river, with its principal tributaries, Fall River, Hat Creek, Burney Creek, and McCloud River, drains a basin of approximately 6,000 square miles. The full development of the river contemplates the use of 2,074 feet of fall out of a total of 2,104 feet. This will be accomplished by means of five stations on Pit River, three of which are now completed, and two stations on Hat Creek, with an aggregate of 429,000 available horsepower.[6]

FEATHER RIVER

Feather River shares with the Pit a preeminent value for the development of water power. The principal developments are located on the North Fork of the river, where a series of six stations is projected. These plants will be operated in conjunction with an irrigation system on the Middle Fork of the river.

While the work has not progressed very far up to the present time, there are opportunities for the development of 500,000 horsepower on the river and its principal tributaries[7] Two plants, the Caribou and the Big Bend, are completed.

[6] A H Markwart, "Half Million Horsepower from Pit River," *Electrical World*, Vol 77, No. 11, March 12, 1921.

[7] *Proceedings of the American Society of Civil Engineers*, May, 1923, Vol. 49, No. 5, p. 936.

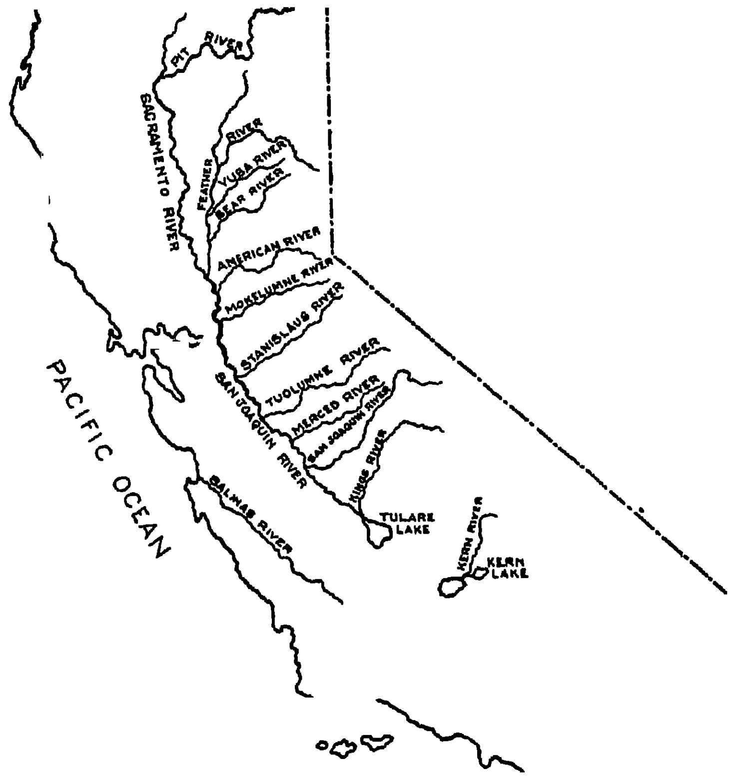


Figure 22 Principal power streams of the valley of California

Middle Fork. Construction of the first of a series of six hydroelectric plants, to cost $8,500,000, is under way on the Middle Fork of the Feather River. The effective head will be 2,400 feet, and the power developed will be 50,000 horsepower. The five other units which are planned will produce about 400,000 horsepower. The total cost is estimated at $45,000,000 to $50,000,000.[8]

Yuba River. The South Fork of the Yuba River is being developed by the Pacific Gas and Electric Company. Sites on the North and Middle forks, when completed, will make

[8] *Electrical World,* April 18, 1925, Vol. 86, No. 16, p. 833.

available about 360,000 primary horsepower and an estimated installed capacity of 755,000 horsepower.[9]

American River. On this river the applications now pending before the Federal Power Commission, if completed, will develop 160,000 horsepower. No licenses for construction have so far been authorized.[10] The present developments on the river aggregate 32,000 horsepower consisting of three plants, 21,500 horsepower, 6,500 horsepower, and 4,000 horsepower, respectively.

THE SAN JOAQUIN RIVER AND ITS TRIBUTARIES

The San Joaquin River is the most important power stream in the south central part of the Nevadas. At the present time all of the developments save one are on secondary streams, such as the North Fork of the San Joaquin, which is occupied by a series of plants of the San Joaquin Light and Power Corporation, and Big Creek, which is utilized by another series belonging to the Southern California Edison Company. In order to meet future demand a survey has been made of the power available in this area. This survey made an estimate of 1,260,000 horsepower, of which 1,120,000 is on the San Joaquin River, 80,000 horsepower on the Kern River, and 21,000 horsepower on the Kaweah River.[11] A construction program has been planned which is expected to furnish a continuous output of 500,000 primary horsepower and 1,234,000 installed capacity.

Mokelumne River. This river has been utilized for many years by one company. Undeveloped sites for which applications are now pending before the Federal Power Commission contemplate the installation of 174,000 horsepower with a primary development of 100,000 horsepower.[12]

Tuolumne River is the source of the Hetch Hetchy power

[9] *Fifth Annual Report of the Federal Power Commission*, 1925, p. 151.

[10] *Ibid*

[11] J D Galloway, *op. cit*

[12] *Fifth Annual Report of the Federal Power Commission*, 1925, p. 151.

supply, a municipal project which serves the city of San Francisco with energy and water. Recently the 80,000 kva. Moccasin Power House has been put into operation. Water for its operation is stored on the Tuolumne River, in Yosemite National Park. The power is carried 98.5 miles to San Francisco. The ultimate capacity of the river is about 170,000 horsepower.[13]

Kings River, second only to the San Joaquin in potential power supply, is as yet undeveloped. The North Fork of the river resembles Big Creek of the San Joaquin, the stream dropping at a tremendous gradient from a plateau basin to the main river and offering feasible heads of 2,000 feet. A complete plan of development has been worked out by the San Joaquin Light and Power Corporation. On the two principal branches of the stream, the Middle and South forks, the city of Los Angeles has made preliminary plans for a series of developments. A conservative estimate for all contemplated developments on Kings River shows a continuous output not less than 400,000 horsepower, provided certain upper storage sites prove to be feasible.[14]

KERN RIVER DEVELOPMENTS

Kern River, the southernmost of the important streams draining from the Sierra Nevada, has a total drainage area of more than 2,000 square miles above the mouth of the Canyon, and ranges from 850 to 14,500 feet in elevation. Much of the drainage area is dry mountain country lying in the foothills or in the arid ridges of the South Fork Basin. The most important power sites are on the North Fork and on the main river below the junction of the North and South forks. Applications for five projects have been made aggregating a total of 87,000 primary horsepower and an installed capacity of 135,000 horsepower.

[13] *Electrical World*, August 1, 1925, Vol 86, No 5, p 207.

[14] *Proceedings of the American Society of Civil Engineers*, Vol. 49, No. 5, May, 1923, p 938.

OWENS VALLEY REGION

The available water power on the Owens River, a stream draining part of the eastern slope of the Sierra, has been under consideration by the city of Los Angeles. The most important sites are in the Owens River Gorge, where the river falls 2,300 feet. With complete regulation a total of 56,000 horsepower could be developed, and, if the smaller streams are taken into account, this total can be raised to 80,000 horsepower for the entire valley.

RÉSUMÉ

The above concludes a brief survey of the more important streams in California. To give a detailed description and to enumerate all the developments in the state would require too lengthy a discussion for the present work.[15]

THE RELATION OF STEAM TO HYDRO IN CALIFORNIA

The economical cooperation of steam and hydro plants in a power generating system must necessarily vary with the local conditions of development. In certain of the southeastern power systems, and, frequently, in the low-head developments of the central states, the hydroelectric plant serves its purpose best when used for stand-by and peak load purposes. In the Pacific States, where water power is abundant and fuel must be imported, effective cooperation dictates that the steam plants be held in reserve to take care of interruptions of service, to carry part of the load for a period of years before the demand increases to a point where the large initial cost of a modern water power plant is justified, to generate energy in years of extreme low water, and to carry a portion of the peak load. In one respect, this last function is the most important. The longer

[15] A detailed description of the hydroelectric developments of California is given in Water Supply Paper No. 493 of the U S Geological Survey.

the transmission line, the more important does this function become. The maximum peak load of a year occurs only once and may not last over an hour. Other peak loads during the year are not so great. If dependence is placed on the water power plant alone, all equipment, including the transmission lines, must be installed to carry a power peak, the energy content of which may be negligible.

THE PACIFIC NORTHWEST

The states of Oregon, Washington, and Idaho share with California and Arizona the distinction of having within their borders immense water power resources. And not only are these resources large and widely distributed, but many of the sites provide the basis for power plants of huge size. If these states are lacking in large reserves of coal and have practically no petroleum, this deficiency is offset, in part at least, by the wealth of water power resources. The problem is not one of seeking power supplies for their industries, but rather of finding a profitable market for the unused water powers that are close at hand.

The Geological Survey estimates the combined water powers of Oregon and Washington at 8,268,000 horsepower, or 24% of the total for the United States, as compared with 4,970,000 horsepower, or 14% of the total, in the state of California.

If the available power in Idaho, much of which could be carried to Washington and Oregon if necessary, be added, the total rises to 10,390,000 horsepower. This is a greater amount than can conceivably be utilized for decades to come, even allowing for the introduction of electrochemical and electrometallurgical industries.

The water powers of this region have been the subject of extensive surveys by both state and Federal agencies. The Federal Power Commission, cooperating with the United States Geological Survey and with state officials, has given considerable study to the Columbia, the Deschutes,

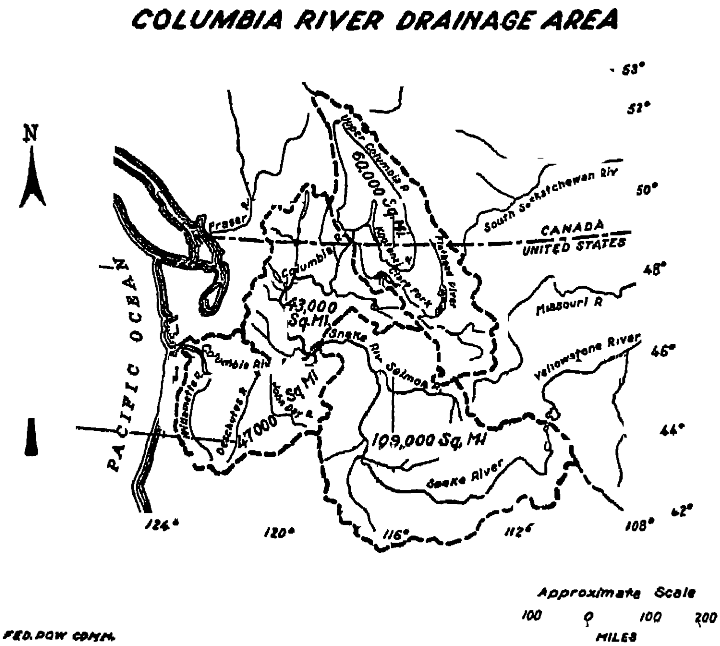


Figure 23: Columbia River drainage basin.

the Trinity, and the American rivers, and the Geological Survey has published reports on water powers in Montana, Idaho, Wyoming, Colorado, and Washington.[16] The more important power streams of this area are described briefly below.

THE COLUMBIA RIVER DRAINAGE BASIN

The most important source of power in the Northwest is the Columbia River and its tributaries, principal of which are the Clark Fork, the Snake, and the Deschutes. Figure 23 shows the drainage basin and its various subdivisions.

[16] Some of the more important publications on the water power resources of this region are listed in the Appendix.

POWER POSSIBILITIES

The potential theoretical power of the Columbia River from Flathead Lake down to Pasco has been roughly figured at 17,000,000 horsepower.[17] This estimate is based on the average annual flow over a total drop of 2,567 feet. As a matter of fact, the power which it will be practical and economical to develop is vastly less. Estimates of such power must be based upon the river flow available for the greater part of the time. For purposes of consistent comparison the nominal stream flow will be used, such as is available either under unregulated or regulated stream flow for 90% of the time. Moreover, only a portion of the total head can be utilized. The Board of Engineers conducting the survey for the Federal Power Commission estimates the usable head at 54% of the gross head, or 1,398 feet.[18]

On the basis of measured past flow, the estimate of economically feasible power is figured at 1,725,000 horsepower, or about one-tenth of that theoretically available in the stream for the period 1913 to 1921.[19] This estimate can, however, be raised materially by the use of storage for stream regulation.

THE SNAKE RIVER BASIN

For the purpose of analyzing the power possibilities of the Snake River, one of the principal tributaries of the Columbia, the stream may be divided into three sections; namely, from its junction with the Columbia in southeastern Washington to Lewiston, Idaho, on the boundary line between the two states; the Canyon section from Lewiston, Idaho, to Huntingdon, Oregon; and the upper course of

[17] *Report to the Federal Power Commission on the Uses of the Columbia River*, 1924, p. 38

[18] *Ibid.*, p 39.

[19] *Ibid.*

the river as it flows westward across the plains of southern Idaho. The upper section of the river, before reaching Huntingdon, is used largely for irrigation of lands in southern Idaho and western Oregon, without which the land would be practically a desert waste.

Irrigation has been rather successful in the Snake River basin, because of several favorable factors, such as suitable climate, fertile soil, and easily accessible water supply. Unfortunately, the unappropriated waters of the river are insufficient to water all the irrigable area. It is estimated that at least a million and a half acres of land are suitable for irrigation if water could be obtained. It seems probable, then, that at some future date all the water above Milner will be diverted for irrigation purposes.

The river from Homestead north to Lewiston will not, however, be entirely devoid of water. Underground runoff, together with seepage losses from adjacent irrigation districts, supplies a continuous flow of 5,000 second-feet.

Undeveloped water power. The topography of the Canyon section of the Snake River is such that developments capable of delivering large blocks of power are feasible. The transportation of raw materials and construction of the dams would be expensive. A railroad would have to be built to carry raw materials, and a considerable hazard to construction would exist because of the likelihood of large floods. Moreover, the necessity of building a dam to provide for the complete utilization of a site would mean carrying a high initial investment until the market could absorb the full output.

The potential water power of this section of the river is estimated by the Geological Survey at 16 dam sites as follows:

	Existing Flow	Regulated Flow
Available 90% of the time	861,000	750,000
Available 50% of the time	1,430,000	1,080,000

THE DESCHUTES RIVER

The Deschutes Basin lies immediately east of the Cascade Range of mountains in Oregon and to the south of the Columbia River. It contains about 9,000 square miles, mostly of rough and well-forested mountain slopes. The main Deschutes River through its entire course of nearly 200 miles parallels the Cascade Range at a distance of about 30 miles from the crest. Numerous tributaries feed the main stream from the west.

The canyon of the lower Deschutes offers good opportunities for the construction of power dams. Sites on the Deschutes, and also its principal tributary, the Metolius, have been investigated by the State Engineer of Oregon and the Federal Power Commission. The report of the commission shows 15 sites in a stretch of 111 miles above the mouth of the Deschutes, with heads ranging from a minimum of 32 feet to a miximum of 270 feet and, in general, from approximately 70 to 140 feet. The capacities of the sites ranged from 11,300 to 83,500 horsepower, but were in general from 25,000 to 50,000 horsepower. The costs ranged from $92 to $205 per horsepower, as estimated, for 85% load factor and delivered to the Columbia. Estimates for four sites on Metolius River showed heads of 75, 260, 400 and 300 feet, respectively, power capacities from 9,100 to 35,500 horsepower, and unit costs from $116 to $252 per horsepower.[20] A total of 471,600 horsepower is available at 15 dam sites.

MARKET FOR DESCHUTES RIVER POWER

The value of large Deschutes power, both in the lower and the upper parts of the basin, depends upon an available profitable power market. Considering first the requirements of the industrial district with Portland as its center, it may be stated that the maximum hourly peak load carried in 1921 by the two public

[20] *Report on the Uses of the Deschutes River,* Federal Power Commission, 1922, p. 43.

service corporations operating in that field amounted to 110,000 horsepower, supplied principally from hydroelectric plants, that additional water power can be made available from the Clackamas, Sandy, Zigzag, and Santiam rivers in Oregon, and the Lewis and Cowlitz rivers in Washington, amounting to over 200,000 horsepower, all within shorter distance to Portland than Deschutes power, and that past growth of peak power demand has been at the rate of about 9,000 horsepower per year.

It may, therefore, be concluded that for the early successful development of large amounts of Deschutes power a market must be created, and that such market must be found principally in metallurgical and chemical industries requiring large amounts of electric power and possibly also for irrigation pumping.[21]

WILLAMETTE RIVER

The water power sites on the tributaries of the Willamette River and the coastal streams are considerable, although not so large in the aggregate as those of the Deschutes-Metolius system. In a report issued by the state engineer the following estimates are given.[22]

Willamette River tributaries	159,200	h.p.
Umpqua River	224,500	"
Rogue	51,800	"
Klamath River	68,000	"

OTHER TRIBUTARIES OF THE COLUMBIA

The estimates given for the Columbia and the Deschutes rivers are based on extensive surveys. Theoretical computations of horsepower available on other tributaries are as follows: Yakima River and tributaries, 34,000 horsepower; Natches River, 57,530 horsepower; Klickitat River, 154,000 horsepower; White Salmon River, 105,000 horsepower; Little White Salmon River, 8,550 horsepower; Lewis River, 78,000 horsepower; Toutle River, 44,000 horsepower; and

[21] *Ibid*, p 51.

[22] *Tenth Biennial Report of the State Engineer to the Governor of Oregon*, 1922-1924.

TABLE 20

KILOWATT HOUR OUTPUT AND INSTALLED CAPACITY*
(Millions of kilowatt hours)

Year	Idaho	Oregon	Washington	Total	Installed Capacity (*Horsepower*)	Percentage Increase
1921	550	468	1,176	2,194	863,939	
1922	616	513	1,286	2,415		10
1923	695	594	1,446	2,735	..	13
1924	793	678	1,503	2,974	958,139	9
1925	752	737	1,818	3,107	1,103,757	5
1926†	812	815	1,699	3,326	1,217,553	7

* *Electrical World*, Vol 87, No 1, January 2, 1926, p 10
† *Ibid.*, Vol. 89, No. 1, January 1, 1927, p 18

Cowlitz River, 175,000 horsepower; On account of topographic or other difficulties, it will probably be found that not all the capacity of these streams can be developed.[28]

THE MARKET POSSIBILITIES

As has been stated, the undeveloped power potentialities are large. Surveys on the Columbia River and its principal tributaries alone disclose the enormous total of 4,000,000 horsepower that could be developed at reasonable costs, provided the market existed. This estimate allows 1,725,000 horsepower for the Columbia River itself instead of the 17,000,000 horsepower which theoretically exists. Moreover, this figure does not take into consideration the power resources of the rivers of the Cascade Range, which are not inconsiderable.

The present power consumption uses but a small fraction of the available resources. The combined kilowatt hour output of the three states, as shown in Table 20, is scarcely half of the output of the state of California. Moreover, the rate of increase in power demand has not been so rapid as in California.

[28] *Water Powers of the Cascade Range*, U S. Geological Survey, Water Supply Papers 253, 313, 369, and 486.

TABLE 21

POSSIBLE MARKET DEMANDS
(Kilowatt hours in millions)

Market	1930		1940	
	K.w. Hrs	H p.	K.w. Hrs.	H.p.
Puget Sound..	1,657	253,400	3,745	572,900
Eastern Washington	845	129,200	1,585	242,500
Idaho-Utah	1,510	230,300	3,112	476,100
Portland..	927	141,800	1,910	292,200
Total	4,939	754,900	10,352	1,583,700

POTENTIAL MARKETS

State and Federal agencies and private interests have conducted extensive surveys of the various rivers, locating the feasible power sites, measuring the flow and gradient, and estimating the potential horsepower. Active applications in these three states now before the Federal Power Commission aggregate 1,184,315 primary horsepower.[24] This extreme activity in survey and development and in proposed development cannot but raise the question of a possible outlet for the hydroelectrical energy which will become available if the projects in contemplation are carried to completion. If this one million primary power is made available and operated at a 60% load factor, it has a possible output of 4,000,000,000 kilowatt hours, which is considerably in excess of the present requirements of the three states combined.

In 1922, Fowler made some estimates of power consumption in the four principal market areas, that is, the Puget Sound market, the eastern Washington market, centering around Spokane, the Idaho-Utah market in southern Idaho and Ogden and Salt Lake, Utah, and the Portland market.[25]

Future estimated loads are given in Table 21.

[24] *Sixth Annual Report of the Federal Power Commission*, 1926, p 16

[25] *Proceedings of the American Society of Civil Engineers.*, Vol. 59, No. 5, May, 1923, pp. 922, 923

In arriving at these figures, he assumes the follow rates of increase compounded annually.

Market	1922-1925	1926-1930	1931-1935	1936-194
Puget Sound. .	11%	10%	9%	8%
Eastern Washington	9	8	7	6
Idaho-Utah .	10	9	8	7
Portland.	10	9	8	7

This assumed annual rate of increase is based upon p performance in these states between 1911 and 1921. actual performance in these states between 1922 and 19 as shown in Table 21, follows rather closely the estim made by Fowler. If this rate of increase is to continue several years in the future, it would appear that, with completion of projects for which application has been m or for which licenses have been granted by the Fed Power Commission, a saturation of the power market in sight.

The possibilities of creating new markets through introduction of industries should not be overlooked. pulp and paper industry is making rapid progress in western states. The use of electrical energy in the me lurgical industries may become an important factor in future. The manufacture of phosphoric acid by the rolytic method has passed the experimental stage, and increasing population will eventually create a demand western phosphates to aid the agricultural industries the Middle West. These developments, however, will occur in the near future. To attempt development a utilization of resources which society does not need a cannot use merely results in a waste of capital and a n direction of human energy. Eventually the needs o growing nation will call for the food crops, the wood pr ucts, and the mineral resources of the Northwest, a when that time arrives, the rivers can be harnessed a brought into service.

VIII

THE DEVELOPMENT OF ISOLATED WATER POWERS

Location of isolated water power sites. Development of isolated water power sites. Remote control stations. Low-cost water power development. Factors in utilization of water power.

THE large concentrations of water powers in restricted localities presents a variety of problems, including those of interstate and international control, coordinated development of power sites with navigation improvements, flood control, and irrigation. Political problems complicate the situation still further. By far the major portion of the water power resources of the United States involve more than the mere economics of building a dam and power house and marketing energy at a rate that will permit a profit on the capital investment.

LOCATION OF ISOLATED WATER POWER SITES

There are, nevertheless, a large number of isolated water power sites, ranging from those with a few horsepower to those of considerable size. These are scattered widely throughout the United States and Canada. Some of these are found in regions where coal is abundant and cheap and where the characteristics of the river and the physical features of the dam sites are such as to leave little or no advantage in water power over steam. Others are found in the central states, where the size and number of these sites are such as to make them almost negligible in contributing to the total power demand. Again, potentialities of considerable magnitude are found in isolated and sparsely

populated regions, such as the rivers of eastern Quebec, the Nelson River in the northern portion of Manitoba, or the water powers of Montana and Idaho.

DEVELOPMENT OF ISOLATED WATER POWER SITES

The utilization of these water powers presents problems of no great difficulty. Consider, for example, the proposal to develop a water power site of from 2,000 to 5,000 kilowatts in the Middle West, in a region already supplied with steam central stations. The public utility corporation or the manufacturing concern requiring additional power need only make a careful survey of the cost of erecting and operating a proposed hydroelectric plant and compare the cost per kilowatt hour from such a plant with that of a steam station, to pass upon its feasibility. Of if the proposed development is independent of the local steam-electric system, the promoter will have to determine the possible market for the new supply of power, the rate at which this power can be sold under competitive conditions, and the time required for the development of a market to absorb the entire output of his plant. Rarely, however, are such independent developments undertaken. The more usual procedure is the installation of a hydroelectric plant by a public utility corporation already supplying the local market, where an increasing power demand necessitates an enlargement of installed capacity.

REMOTE CONTROL STATIONS

Technical progress in the production and transmission of electricity is constantly bringing small water power sites within the range of economic usefulness. The remote control station, for example, makes possible the operation of a small hydroelectric plant from the main station without the need of a superintendent at the outer plant, thereby reducing somewhat the labor costs. The adaptability of

such stations for peak-load service has been noted previously. The carrying costs of a hydroelectric plant, when idle, are usually far less than for a steam plant of corresponding size. The extension of transmission lines through a territory brings many small water power sites within an economical transmission range which, together with the remote control feature, makes their utilization profitable as feeders to the lines.

LOW-COST WATER POWER DEVELOPMENT

A different type of isolated water power development is that located in a sparsely settled community. Here no general power market exists. In such a case, developments usually are undertaken by a manufacturing industry which requires cheap power. Where the natural conditions favor a low-cost development, and where the isolation of the country removes the possibility of competitive bidding by industries which can afford to pay considerably more for the power, a development of this nature may take place. Conspicuous examples of this are the aluminum plants in eastern Tennessee and on the Saguenay River in Quebec. Other possibilities might be suggested. The production of phosphoric acid by the pyrolytic method, for example, should be studied in connection with the water power potentialities and the phosphate beds of Idaho. The Nelson River in the northern portion of Manitoba offers possibilities of low-cost development. Can this low-priced power be applied to a manufacturing industry? Its remoteness from markets, no doubt, precludes any development for decades to come; nevertheless, the suitableness of this stream for industries requiring cheap power is such that it may yet attract serious attention.

FACTORS IN UTILIZATION OF WATER POWER

The item of power, however important it may be, is but one of the many factors that the producer of goods has to

consider. The distribution of population, labor supply, markets, and raw materials together play the most important part. The utilization of water powers, large in the aggregate, in the remote areas is a concern for generations far in the future.

IX

PUBLIC CONTROL OF WATER POWERS

Public opinion in favor of social control Legal basis of public control of water powers, public lands. Navigable waters International boundary streams. Administration of water power laws previous to 1920 War Department. The Department of the Interior. The Department of Agriculture. Unsatisfactory conditions of water power development under divided authority. Need for a single executive agency. The Federal Power Commission. Jurisdiction of the Federal Power Commission Duties and functions of the Federal Power Commission. General administration of water powers Supervision over design, construction, and operation of project works. Regulation of financial policies Regulation of rates and services. Valuation of properties of licensees. General investigations Certain defects of the act Accomplishments under the Act of 1920. Conclusion. Canadian water power legislation. The Dominion Water Power Act

PUBLIC opinion in the United States and Canada stands unequivocally for a public interest in water power development. This opinion is expressed in the laws of the state and provincial governments, in Federal law in the Act of 1920, in various proposals now before the public which seek to enlarge still further the control of government over water power development. One needs only to recall the vigorous effort being made by one group in Congress under the leadership of Senator Norris to operate Muscle Shoals under government direction, the proposals of Governor Smith of New York to develop the vast water powers of that state under governmental supervision, and the efforts to have the Federal Government itself harness the Colorado River. True, these are but proposals, and some of them probably have only a remote chance of being carried out, but the very vigor with which these proposals are advanced and the degree of support they receive from the public are indications that the American people are determined to secure and retain some measure of control over hydraulic development. This state of mind is indeed significant when

one considers that practically no public control was exercised over those vast resources of national wealth which first attracted the exploiter—the forests, the coal lands, petroleum, and the vast areas of fertile soil. This guardianship over the water powers seems to indicate definitely a change in public opinion toward a closer supervision of the disposition of the natural resources of the country.

LEGAL BASIS OF PUBLIC CONTROL OF WATER POWERS

The power of Congress to enact legislation exercising control over the development of water power on public lands and reservations of the United States, in navigable waterways, and in streams forming or crossing international boundaries is derived from three definite provisions of the Constitution.

Public lands. Article 4, section 3, of the Constitution gives Congress the power "to dispose of and make all needful rules and regulations respecting the territory or other property of the United States." Since the lands of the United States are not subject to condemnation or to any form of disposition by state authority, the power of fixing conditions under which lands necessary for power development may be occupied and used for such purposes rests with Congress alone. The total area of public lands thus owned by the United States is approximately 450,000,000 acres, a large proportion of which is found in the 11 western states wherein are contained the major water power resources of the country. Power resources on these lands and on navigable and international streams approximate 85% of the country's potential water powers, and over these the Federal Government has exclusive jurisdiction. In some instances the absolute proprietary right of the United States in the waters on public lands has been limited by previous acts of Congress, as, for example, in the granting of water rights for "mining, agricultural, manufacturing, and other purposes" which was authorized by the Act of

June 26, 1886, section 2339 of the Revised Statutes. The Act of 1870 authorized vested and accrued water rights in the lands of the United States for irrigation purposes. Under act of March 3, 1891 (26 Stat. L., 1095, 1101), records were made of all water rights granted and security provided for the maintenance of these vested rights. These rights were again affirmed in the Water Power Act of 1920, which declares as follows:

> That whenever, by priority of possession, rights to the use of water for mining, agricultural, manufacturing, or other purposes have vested and accrued, and the same are recognized and acknowledged by the local customs, laws, and decisions of courts, the possessors and owners of such vested rights shall be maintained and protected in the same; and the right-of-way for the construction of ditches and canals for the purposes aforesaid is hereby acknowledged and confirmed.

Legislation bearing directly upon the subject of water power regulation on public lands and reservations was embodied in the Act of February 15, 1901 (31 Stat. L., 790) which gave to the Secretary of the Interior the power to grant the use of rights of way over public lands especially applied to "water plants, dams, and reservoirs." This law, however, did not give certain tenure to the grantee in that the license was revocable by the Secretary of the Interior, and also, that the lands to which the rights applied might still be patented by others. The uncertainty of tenure under this act tended to discourage development of water power sites, and it was not until the Act of 1920 removed these conditions that development again proceeded to any extent.

NAVIGABLE WATERS

The jurisdiction of Congress over the power developments on navigable waters of the United States is exercised under the provisions of Article 1, section 8, of the Constitution "to regulate commerce with foreign nations and among the several states." While this power over navigable

streams was early recognized with respect to navigation through various acts granting aid to states in the improvement of rivers and harbors, it was not until the Rivers and Harbors Act of July 5, 1884, (23 Stat. L., 133)[1] that legislative control over the erection of structures in navigable waters was first asserted. This law was designed to maintain unhampered navigation on navigable waters, and the Secretary of War was empowered to remove any obstacles to free navigation.

The first specific act of Congress for the development of water power is contained in a law also dated July 5, 1884 (23 Stat. L., 154) authorizing the construction of a dam and other works for a water power development. The right to control navigation was asserted in this act by requiring the dam to be so constructed as to permit the free passage of logs and rafts, and also to allow the national government to construct a suitable lock for navigation. The law of July 5, 1884, was followed by 30 special acts within the following 22 years granting, with certain restrictions, the right to build dams and other works for power development purposes.

A subsequent act of Congress, June 21, 1906, provided certain general conditions which should apply to all specific grants authorized. The conditions required were the approval by the Chief of Engineers of the plans and specifications and the maintenance of locks and other navigation facilities without expense to the United States. The permit might be repealed by act of Congress at any time in the event of the licensee failing to comply with a lawful order of the Secretary of War or of the Chief of Engineers.

INTERNATIONAL BOUNDARY STREAMS

The development of power sites on streams forming or crossing international boundaries requires the cooperation and consent of both the sovereign powers involved. In the

[1] M Conover, *The Federal Power Commission*, Service Monograph of the United States Government No. 17, Institute for Government Research, Johns Hopkins Press, Baltimore, 1924, p. 21.

case of the United States, questions of international cooperation on power projects arise only with Canada. The two streams, the Rio Grande and the Colorado, which concern the United States and Mexico involve only problems of irrigation and flood control. When the use of an international stream for power development or other purposes is contemplated, the common consent of the two countries can be obtained only through the arrangement of a treaty establishing unity of legal control. Under the provisions of Article 2, section 2, of the Constitution, the sole power of making and enforcing treaties rests with the President of the United States and the Senate.

The erection of hydroelectric plants at Niagara Falls and the consequent diversion of water from above the falls on both the American and the Canadian sides of the international boundary aroused a fear that such diversions would injure the scenic beauties of Niagara Falls. Hence on June 29, 1906, Congress passed the Burton Act limiting the diversions on the American side to 15,600 cubic feet per second, and recommended the negotiation of a treaty with Great Britain covering the subject of navigable waters. As a result of this recommendation an International Joint Commission was created with jurisdiction over diversions from boundary streams for other than domestic, sanitary, or navigation purposes, and over constructions in streams forming or crossing the boundary which would affect the level of waters on the other side of the boundary. The treaty also clothed the commission with investigatory powers for purposes of examining into and reporting on any questions or matters of difference arising along the common frontier.

In the case of the Niagara River the treaty provided for "maximum daily water diverted from the river for power purposes at the rate of: 36,000 cubic feet per second to Canada and 20,000 cubic feet per second to the United States." These prohibitions do not apply to diversions of water for navigation or for sanitary or domestic purposes.

Applications for the construction, maintenance, and operation of water power plants must receive the approval of the International Joint Commission before being passed upon by the Federal Power Commission.

ADMINISTRATION OF WATER POWER LAWS PREVIOUS TO 1920

The administration of the laws passed by Congress relating to water power development was naturally referred to the executive department whose interests were involved in each particular case. Hence, in the period from 1789, when the first act was passed laying the foundation of Federal control, to 1920, when the Federal Power Commission was organized, the duty of carrying out the provisions of the various laws fell upon the War Department, the Department of Interior, and the Department of Agriculture. In order to understand more fully the development of water power control culminating into the Federal Power Act of 1920, the extent of jurisdiction of each of the executive departments will be described briefly.

WAR DEPARTMENT

The acts of Congress regulating navigable streams are administered by the War Department through the Corps of Engineers. The early acts of Congress were concerned practically only with the improvement of rivers and harbors for navigation purposes, and it was not until the building of railroads, with the consequent need of bridging rivers, that the War Department was called upon to exercise its authority in regulating the plans and specifications of such bridges or other structures which affected the navigability of a stream. In 1888 Congress authorized the Secretary of War "to grant leases or licenses for the use of water powers on the Muskingum River at such rate and on such conditions and for such periods of time, as may seem to him just, equitable, and expedient: Provided, That the leases or

licenses shall be limited to the use of the surplus water not required for irrigation." Thus the way was paved for direct administrative control by the War Department of water powers on navigable streams. Several similar laws were enacted during two succeeding decades. The power of the War Department over navigable streams was further increased in 1890 by empowering the Secretary to prohibit the erection of structures of any kind which would impair navigation in any of the navigable waters of the United States. Several more acts further served to establish the authority of this department.

THE DEPARTMENT OF THE INTERIOR

The administration of water power by the Department of the Interior is exercised principally through the United States Geological Survey and the General Land Office. As the authority of the War Department covers the water power sites on navigable streams, so that of the Department of Interior is concerned with the water powers on public lands, reservations, national monuments and, until 1912, on forest reserves. Active control of water power development began in 1891 when by act of March 3 of that year (26 Stat. L., 1101) the Secretary of the Interior was authorized to grant permits for canals and reservoirs in connection with irrigation projects. By act of January 21, 1895 (28 Stat. L., 635) the Secretary of the Interior was authorized to grant permits for rights of way on public lands not within the limits of national parks, forest, or military or Indian reservations. This power was extended by act of May 24, 1896 (29 Stat. L., 720), to include use of rights of way upon public lands and reservations for "electrical purposes." On May 11, 1898 (30 Stat. L., 404) the use of rights of way for irrigation was extended to include power development in connection with irrigation. The Secretary's power was further increased by act of February 15, 1901 (31 Stat. L., 790) authorizing him "to permit the use

of rights of way through the public lands, forests, and other reservations of the United States" and through certain parks "for electrical plants, poles, and lines for the generation and distribution of electric power, and for telephone and telegraph purposes, and for canals, ditches, pipes and pipe lines, flumes, tunnels or other water conduits, and for water plants, dams, and reservoirs used to promote irrigation or mining or quarrying, or the manufacturing and cutting of timber."

THE DEPARTMENT OF AGRICULTURE

The Department of Agriculture became involved when the forest reserves were transferred to it from the Department of Interior. Control of the water powers, however, still remained with the Secretary of the Interior until the passing of the Act of March 4, 1912 (36 Stat. L., 1253). This law gave to the Secretary of Agriculture the power to grant easements for rights of way under general regulations to be fixed by him. The easements were to permit rights of way "for electrical poles and lines for telephone and telegraph purposes," across national forests, reservations, and public lands. The easements were to be good for 50 years. The importance of the Department of Agriculture in its relation to water power control is noted when one considers that one-third of the water power resources of the United State, and one-half of the water power resources of the West are in National Forests.

UNSATISFACTORY CONDITIONS OF WATER POWER DEVELOPMENT UNDER DIVIDED AUTHORITY

The growth of legal precedents and principles under three separate departments resulted in a state of affairs which was highly unsatisfactory and tended to discourage the development of these water powers under private initiative. The uncertainty of tenure of license, the lease being revoc-

able at the will of the Secretary, made the hazards to investors too great to risk the employment of private capital in such enterprises. That this power of revoking a license at will was an important factor in discouraging investments is evidenced by the action of the Secretary of the Interior in 1909 who, two days before his going out of office, revoked 25 permits. The reason given for this raid on water power investments was not that the permittees had committed any wrongful act, but that the department had adopted new rules and the Secretary wished to bring previous permittees under them.[2] From time to time efforts had been made to correct this condition through legislation, but all such attempts failed. In the Department of the Interior an awkward situation existed in that a right of way upon public land did not prevent the patenting of this same land by a settler for agricultural purposes, with the possibility of friction between the two parties concerned. Moreover, a right of way could not be obtained "where it is intended to use the water exclusively as a means of creating power to run an electric or manufacturing plant or in hydraulic or placer mining, although when a right of way was once obtained for irrigation purposes it might also be used for these other purposes in a subsidiary way."[3]

Another defect in the legislation of this period was that the executive departments were not authorized to set a time limit within which power projects should be completed. This opened the way for speculators and prospective water power monopolists to gain control of sites which in time would become very valuable.

NEED FOR A SINGLE EXECUTIVE AGENCY

That the executive departments of the government were keenly aware of the unsatisfactory state of affairs is evi-

[2] Pierce, *Federal Water Power Regulation*, 64th Congress, First Session, Senate Document 468, p. 4.

[3] Secretary of the Interior, *Annual Report*, 1899, p. xiii.

denced by frequent references to the subject in various reports submitted from time to time.[4]

In 1917 the Secretary of Agriculture suggested a water power commission:

Legislation which will make it possible to safeguard the public interests, and at the same time to protect private investors, should result in securing cheaper water power and in conserving the coal and the fuel-oil supply. Since three departments of the government are vitally concerned in water power legislation and its possible terms and would be vitally affected by the administrative handling of matters under such legislation, it would seem desirable to consider whether it is feasible to devise an executive body on which the three departments will be represented and which will be able to utilize to the best advantage all the existing agencies.[5]

In that same year, June, 1917, the chief engineer of the Forest Service[6] recommended:

. . . . that the administration of all water powers over which the Federal Government has control be centered in a Federal Water Power Commission, consisting of the Secretaries of Agriculture, Interior, and War, and the Attorney-General, together with one appointed member to serve as executive for the commission. By this means the policies of the several departments could be made uniform, their action correlated, and duplication of work avoided. It is believed also that by this procedure more satisfactory legislation, particularly with respect to navigable streams, could be secured.

He also submitted to the Secretary of Agriculture a detailed memorandum embodying the principles which were later incorporated in the Federal Power Act of 1920. The secretary approved this plan and sent it to the President.

[4] See (*a*) Commissioner of the General Land Office, *Annual Report*, 1909, p 62, *Annual Report*, 1911, p. 103; (*b*) Secretary of the Interior, *Annual Reports*, 1911, pp 12-15, 1912, pp 14-31; 1913, pp. 23-25, 1914, pp 16-18; 1915, pp 18-21, (*c*) Federal Power Commission, *Annual Report*, 1921, pp 46-47; (*d*) Forester, *Annual Report*, 1910, pp 371-372; 1913 p 174, (*e*) Commissioner of Corporations, *Report on Water Power Development in the United States*, March 4, 1912, chapter ii, "Relation of Water Power to the Public," pp 209-211.

[5] Department of Agriculture, *Annual Report*, 1915, pp 47-48

[6] O C. Merrill.

THE FEDERAL POWER COMMISSION

The act creating the Federal Power Commission was approved June 10, 1920. The commission is composed of the Secretary of War, the Secretary of Interior, and the Secretary of Agriculture. These appoint an executive secretary. who is the only official employed directly by the commission. The remainder of the staff is made up of members of the three departments concerned from which officers and employees are temporarily transferred when needed to conduct investigations or perform other duties for the commission. This form of organization has not been entirely satisfactory, and the shortcomings will be pointed out under a discussion of the defects of the act.

JURISDICTION OF THE FEDERAL POWER COMMISSION

The Federal Power Commission has jurisdiction over the public lands and reservations of the United States only, in so far as the question of water power development is involved. Its authority does not cover cases where irrigation or other projects not involving power development are concerned. Its jurisdiction over power developments on navigable streams is absolute. Navigability is defined by the Act of 1920 as "those parts of streams or other bodies of water over which Congress has jurisdiction under its authority to regulate commerce with foreign nations and among the several States, and which [are navigable] either in their natural or improved condition notwithstanding interruptions between navigable parts of such streams or waters by falls, shallows, or rapids; together with such other parts of streams as shall have been authorized by Congress for improvement by the United States or shall have been recommended to Congress for such improvement after investigation under its authority."

Its jurisdiction also extends to those nonnavigable tributaries of navigable waters in which power developments,

by altering the natural flow, would affect the capacity of navigable rivers.

DUTIES AND FUNCTIONS OF THE FEDERAL POWER COMMISSION

The Act of 1920 placed under the jurisdiction of the commission fully 85% of the potential water powers of the United States. Also, it conferred upon this body broad powers of administration and regulation over the water power resources, their development, and the fixing of rates for hydroelectrical energy. The principal duties and powers can be grouped under the following heads:

1. General administration of water powers
2. Design, construction, and operation of project works
3. Regulation of financial policies
4. Regulation of rates and services
5. Valuation of properties and licenses
6. General investigations
7. Special investigations

GENERAL ADMINISTRATION OF WATER POWERS

All proposals for the construction of power plants on the waters under the jurisdiction of the Federal Power Commission must be approved by this body, which issues a license to the corporation desiring it. However, the conditions surrounding the issuance of a license for the construction of a plant are so numerous and exacting that, in carrying out its duty, the commission virtually becomes administrator of all water power resources under its control.

The application for a license is ordinarily preceded by an application for a temporary permit usually of three years' duration. The purpose of the permit is twofold. It allows the applicant to conduct preliminary surveys on the proposed power sites, make estimates of developmental and construction costs, draw up the necessary plans and specifications required by the commission, study the probable market for the power, make financial arrangements and, in

other ways, gives the applicant an opportunity to judge whether or not the proposed project is feasible or likely to be a profitable investment. At the same time such a permit gives the party to whom it is issued priority rights in applying for a license.

When an application for a preliminary permit is received, the commission is required to give notice to "any State or municipality likely to be interested," and to publish notices of such an application for eight weeks. This provision has the double intent of allowing any local government to file objections if, in any way, the granting of a license will affect the public interest adversely, or it will allow the local government to file application for a permit to develop the site, which application must be given preference by the commission over those of private corporations. While this provision is not intended to mean that the government prefers to see water powers developed by public rather than by private agencies, it serves to safeguard the public interest against undue private control. In case application is made for a site on public lands, the commission notifies the local land office, and upon granting the permit, all lands involved in the development of the site are to be withdrawn from entry. If necessary, the commission may hold hearings, call witnesses, administer oaths, and require the furnishing of such information as it considers necessary in passing upon an application for a permit or a license.

When the permittee wishes to apply for a license, he is required to furnish with his application:

> 1. Such maps, plans, specifications, and estimates of cost as may be required for a full understanding of the proposed project. Such maps, plans, and specifications, when approved by the commission shall be made a part of the license; and thereafter no change shall be made in said maps, plans, or specifications until such changes shall have been approved and made a part of such license by the commission.
>
> 2. Satisfactory evidence that the applicant has complied with the requirements of the laws of the state or states

within which the proposed project is to be located with respect to bed and banks and to the appropriation, diversion, and use of water for power purposes and with respect to the right to engage in the business of developing, transmitting, and distributing power, and in any other business necessary to effect the purposes of a license under this act.

3. Such additional information as the commission may require.[7]

Licenses are granted for the construction, operation and maintenance of dams, water conduits, reservoirs, power houses, transmission lines, and other necessary works, for a period not exceeding 50 years. During this period the commission exercises general supervisory control over any actions of the licensee which affect the public interest. No transfer of any license can be made without written permission of the commission; contracts for the delivery of power beyond the date of expiration of the license cannot be made except on approval of the commission. Where a licensee is benefited by the construction of storage works or other headwater improvements in the stream by the government or by another licensee, the commission is authorized to apportion the annual expenses of the improvement among the several beneficiaries in accordance with the benefits received.

In order to carry out these administrative duties, the commission is authorized to make all the rules and regulations necessary and to submit annually to Congress a report of permits and licenses issued.

SUPERVISION OVER DESIGN, CONSTRUCTION, AND OPERATION OF PROJECT WORKS

In addition to its general administrative duties, the Federal Power Commission is required to approve the general scheme of development of a project, to pass upon the plans and specifications of the works, and to lay down rules and

[7] The Federal Water Power Act (Vol. 41, Stat. L., p. 1063), published in the *Third Annual Report of the Federal Power Commission*, 1923, p. 38.

regulations for operation and maintenance. The power thus granted is comprehensive in scope. First, the commission is authorized to require that "the project adopted . . . . shall be such as . . . . will be best adapted to a comprehensive scheme of improvement and utilization." This enables the commission to make all plans to conform to a development which will result in the most effective utilization of a stream or system of streams. The importance of this power cannot be overestimated. Under unrestricted private development the location of a given project might serve to destroy the usefulness of other nearby sites and thereby also destroy part of the potential power of the stream. A comprehensive scheme of development, as is possible only under the supervision of the Federal Power Commission, is clearly necessary for such important streams as the Tennessee River, the Columbia River system, and the Colorado River, as well as for a large number of smaller streams.

Not only must the general scheme of development be approved by the commission, but also detailed plans, maps, and specifications must be submitted by the applicant for approval. The most effective development of a stream requires that its uses for irrigation and navigation are not impaired needlessly because of power developments. By taking thought the stream can be made to serve all of these purposes and its economic value greatly enhanced. The duty of the commission to approve the plans and specifications gives it power to require navigation locks, fishways, and so forth wherever it deems these appurtenances necessary.

Finally, the interests of the consumers of power are to be safeguarded by a provision in the law which enables the commission to require extensions of equipment whenever market conditions warrant such installations. Moreover, the supervisory powers include authority to prescribe rules and regulations for the protection of life, health, and property, in connection with the construction and operation of project works.

REGULATION OF FINANCIAL POLICIES

The Federal Power Commission also exercises close supervision over the financial policies of a licensee. Before a license is granted to an applicant, he must submit a detailed estimate of the cost of the project. Within a reasonable time after the project is completed, the owner of the license must file with the commission a statement showing the actual legitimate cost of construction of the project, together with the price paid for water rights, rights of way, lands, or interest in lands. Valuations for the purpose of rate making shall include the actual cost of construction of the works only, and cannot be made to include good will or going value, or value based on prospective revenues. To keep the commission informed regarding the financial status of the licensees, a uniform system of accounting has been prepared. Moreover, reports giving full information as to assets, liabilities, capital investment, gross receipts, and all other receipts and disbursements must be filed with the commission at stated times. The books of the company may be examined by the commission whenever it so desires. Finally, provision is made for the apportionment of surplus earnings to amortization reserves.

REGULATION OF RATES AND SERVICES

The policy of the Federal Power Commission is to cooperate with the states in the administration of the Water Power Act, and not to attempt to supplant state authority. An applicant for a license is required, first of all, to show that he has complied with all the laws of the state in which his project is located before he may secure a license. In the matter of rate making and the conditions of services to be rendered, the commission has jurisdiction over intrastate business only when no rate-making body exists in the state, or in interstate business whenever the states concerned have not the power to act individually or cannot reach mutual

agreement. In the former instance the Federal Power Commission is rarely called upon to exercise its authority, since all but two states have public service commissions or similar regulatory bodies. In the latter instance, however, circumstances arise where regulation by a Federal authority becomes extremely important. The interstate aspects of power development at Muscle Shoals, on the Colorado River, the St. Lawrence River, the Columbia River system, and the Susquehanna River, for example, are too weighty to be ignored. "It becomes important to determine by whom these interstate energy transfers are to be regulated; but more important whether they are to be regulated at all."[8]

The Conowingo development on the Susquehanna River furnishes an excellent illustration of the need of a Federal regulatory agency. In this instance the development has been undertaken by a Pennsylvania corporation on a site in the state of Maryland, and the power transmitted to, and retailed in, Philadelphia. In order to obtain the largest possible freedom from state regulation the following corporate relationships were arranged.

1. Philadelphia Electric Power Company (domiciled in Pennsylvania, hence its security issues are not subject to scrutiny by the Pennsylvania Public Service Commission) leased part of the Conowingo property in Pennsylvania to

2. The Susquehanna Power Company of Maryland, which in turn leased this property, together with all Maryland properties, to

3. The Susquehanna Electric Power Company of Maryland, which company contracted to sell the power at wholesale to

4. The Philadelphia Electric Company.

Under this arrangement both the issuance of the securities and the regulation of rates were beyond the control of the public service commissions of the states of Pennsylvania and Maryland.[9]

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[8] O C. Merrill, "The Federal Power Commission at Conowingo," *The New Republic*, Vol. 47, No. 599, May 1, 1926, p. 20

[9] The Supreme Court has decided in a gas case that where a company generates energy in one state, transports it to another, and wholesales it

If the states were helpless to control security issues and rates in this instance, the Federal Power Commission, with jurisdiction over navigable streams, was clothed with full authority to scrutinize and regulate these conditions It could, therefore, determine the actual legitimate investment, consisting of pre-license and later construction costs, and fix rates on this basis; it could also pass upon the financial structure of the project and make such provisions as were necessary to safeguard the interests of both the stockholders and the consumers. In the case of the Conowingo development certain changes in the method of financing were required by the commission in order to protect the interests of the stockholders. The action of the Federal Power Commission in this case clearly demonstrates that:

1. In interstate streams, the jurisdiction of state agencies is inadequate, and a Federal agency is necessary to exercise control.

2. There is need of authority to review the financial structure and plans of a public utility corporation.

3. There must be effective limitation of capital accounts for purposes of rate making to the actual legitimate investment. Authority to limit capital accounts is granted by the Act of 1920.

VALUATION OF PROPERTIES OF LICENSEES

The fundamental purpose of the Act of 1920 in giving to the commission the power to make valuations of the hydroelectric developments of licensees was to protect the consumers against excessive rates. For that purpose, the "actual legitimate investment" in the properties is made the basis for rate making, as explained above. There is, moreover, another reason for making valuations. Under the terms of the act the government reserves the right to renew the license to the original owner upon terms satisfactory to both, to give the license to another, or itself to buy the property.

there for retailing purposes by another company, the public service commission of the second state has no power to fix the price which the retailing company must pay for the power (265 U S, 298, 44 Sup. Ct, 544). This is the relationship between companies 3 and 4.

In any case the value of the property must be known, and the basis of this value, as has been stated above, is the actual investment. "Going value," or value based upon present or probable earnings, cannot be considered. To accomplish this purpose, it is the duty of the commission

1. To require the filing of statements showing the cost of construction of the project works and the price paid for water rights, rights of way, lands, and interests in lands.
2. To make a valuation of all projects brought under license which have been constructed in whole or in part prior to application for a license.
3. To make a valuation in case of condemnation of the properties of a licensee by the United States.
4. To determine the net investment and severance damages in the event that properties of a licensee are taken over by the United States at the termination of a license period.

GENERAL INVESTIGATIONS

In addition to its duties of general administration and regulation of water power developments, the commission is authorized to undertake general investigations and to collect data concerning the water power resources of the United States. This permits a very comprehensive study of the economic and conservational problems in the utilization of water power resources. Under this authority, a whole river system or a drainage basin can be studied, with the view of planning a comprehensive development which will utilize all the resources of the stream—irrigation, navigation, and water power. If this task were left entirely to private initiative, it would result, in many cases, in the development of one or a few sites to the detriment of the effective development of the whole watershed. Frequently a stream is too large to be surveyed by a private corporation, with the result that if development of a single site is undertaken without reference to the stream as a whole, later surveys will show that part of the potential power has been destroyed

by a previously erected plant that was unwisely placed.

The meager information now available regarding the capacity, cost of development, and the market possibilities of the great number of power sites makes it imperative that the Federal Power Commission should undertake investigations along these lines and gather data concerning individual sites as well as for entire watersheds.

Up to the present time several investigations have been completed. The most important of these surveys are the Columbia River in Washington, Idaho, and Montana, the Deschutes River in Oregon, the results of which have been published, and the Trinity, American, and Stanislaus rivers in California. In all these surveys the commission acted in cooperation with officials of the states interested.

It is unfortunate that, under the provisions of the Act of 1920, the Federal Power Commission is not permitted to use all the moneys collected from license charges for the conduct of investigations. While the special surveys on the rivers mentioned above are indicative of what ought to be done, they represent studies of a very limited portion of the country's water power resources. What is needed is a comprehensive survey of the water resources of the streams of the United States in order to enable the Federal Power Commission to pass intelligently upon the many applications for power projects that are constantly being filed, and to have information which will enable it to determine whether the projects for which it grants licenses conform to an economic plan of river development for purposes of irrigation, navigation, flood control, and power.

Such surveys are impossible with the limited financial resources of the commission, and, until the act is so amended that the moneys received from license charges, instead of being diverted to the Treasury, are applied to a program of surveys, the commission cannot avoid making mistakes in licensing the development of rivers for which it has been unable to make surveys and draw up definite plans.

CERTAIN DEFECTS OF THE ACT

In the first few years of its administration certain defects have appeared in the Federal Power Act which have hampered greatly the work of the commission. Most serious of these, perhaps, is the fact that the commission has no full-time personnel except the executive secretary and the engineer officer. With more water power development under way at the present time than at any previous period in history, the greater part of which comes within the provisions of the Water Power Act, the commission is forced to borrow for its administrative work such men as the Departments of Agriculture, War, and Interior are willing to loan and able to spare. In many cases the commission has been compelled to depend for examination and reports of applications upon the field officers of the departments—men who are not directly responsible to the commission. This arrangement is unsatisfactory both to the commission and to the departments involved, as well as to the applicants for licenses. It has resulted in long delay on important projects. In many cases it has been obliged to omit the performance of important duties required by the act, or to suspend the issuance of licenses.

This lack of personnel also affects very seriously the work of the accounting division. The cumulative character of the commission's supervisory work makes it difficult for two accountants to examine thoroughly the valuations and costs of projects submitted by applicants, with the result that the provision of the act regulating the financial operations of the licenses to conform to the best interests of the public cannot possibly be carried out.

In the first annual report, the commission states that:

> What is seriously needed in the interest of adequate administration of the act is a small organization of trained and experienced men capable of meeting intelligently the important and perplexing engineering and economic problems which are constantly arising and upon the correct solution of which will depend

the value of legislation and, in no small degree, the future of the electric power industry.[10]

A second defect that has appeared is the failure to provide the commission with administrative authority over water power grants issued under prior laws. As a result other agencies have been required to continue their independent activities, and these activities are not controlled by a common plan or subject to a common direction. Hence, the chief purpose of the act, the creation of a single executive agency, has not been fully accomplished. This defect cannot be cured until the law is so amended as to provide the proper authority to the commission, together with an appropriation large enough to employ the necessary personnel to carry out this work.

A third defect, the failure to allot the monies received from license fees for survey work, has been discussed previously under the section on "general investigations."

ACCOMPLISHMENTS UNDER THE ACT OF 1920

Under the laws existing previously to the Act of 1920 the risks and uncertainties attending water power development were so great that the construction of projects practically ceased. These conditions were entirely changed under the new law. Immediately following the approval of the act a flood of applications was received. Projects long delayed were immediately approved and construction work started. During the first six years of its existence the commission received applications involving a net installed capacity of 24,755,000 horsepower, of which amount approximately 13,650,000 is primary horsepower. In this same period licenses have been granted for a total installed capacity of 5,242,175 horsepower. When one recalls that previously to 1920 the capacity of all water power plants amounted to only 9,500,000 horsepower, the improved character of the legislation becomes apparent.

[10] *First Annual Report of the Federal Power Commission*, 1921, pp. 50, 51

CONCLUSION

The economic consequences of the law of 1920 were several. Investment of capital in legitimate water power enterprises was encouraged. Corporations or persons who were actually interested in the construction of power projects, and who were not investing for speculative purposes, were assured that the investment of capital would no longer be placed in jeopardy by leases of uncertain tenure or by arbitrary rulings of a government bureau. Public supervision tended to assure wise and economical investment of capital resources and provided for effective use of the natural resources of our rivers with attendant social economies.

CANADIAN WATER POWER LEGISLATION

The water power resources of Canada are under the jurisdiction either of the Dominion Government or of the provincial governments, depending upon the location of the site. The Parliament of Canada has administrative authority over water powers on public lands, in the Territories, and on Indian lands. The provincial governments of British Columbia, Ontario, Quebec, New Brunswick, Nova Scotia, and Prince Edward Island have jurisdiction over the water powers within their own boundaries.

THE DOMINION WATER POWER ACT

The general plan of the Dominion Water Power Act is to provide that the water powers on lands of the Dominion and the additional Crown lands essential to the development or protection of such water powers are to remain vested in the Crown, no outright sale of them being permitted, but they may be leased to any approved licensee for a definite term of years upon certain specified conditions.

The regulations governing acquisition of a license and the duties and obligations of the licensee to the government and

to the consuming public parallel in many respects the regulatory features of the Federal Water Power Act of the United States.

The principle of public control, as exercised by the Dominion Government, is also followed by all the provincial governments, although in the degree of control and the details of administration they may differ among themselves.[11]

[11] For a detailed discussion of water power legislation of Canada, see J B Challies, "Water Powers of Canada, Their Nature, Extent and Administration," *Transactions of the First World Power Conference,* Vol I, 1924, pp 204-237.

X

PUBLIC OWNERSHIP PROJECTS

A social policy in regard to the control of water powers. The Giant Power plan The Hydro-Electric Power Commission of Ontario Origin of the Hydro-Electric Power Commission Organization and powers of the Commission. Financial structure of the Hydro-Electric Power Commission. Activities and criticisms of the Commission Muscle Shoals, proposed development; the nitrate plants. Importance of Muscle Shoals as a source of power. Cost of power. Present problem in the disposal of Muscle Shoals. Production and importation of nitrogen into the United States Atmospheric nitrogen Nitrogen needs of the United States; agricultural; military; industrial Summary of nitrogen needs The future of atmospheric nitrogen The public ownership proposal Other public developments.

THE social control of the water power resources of the nation looms in importance because of its relationship to the public control or regulation of electric utilities in general. The increasing use of the electric motor in the manufacturing industries and the rapid growth of central station output, from 10 billion kilowatt hours in 1910 to over 75 billion kilowatt hours in 1927, is an indication of the significance of electric power. This increase in the output of electrical energy is accompanied by a definite trend toward centralized management, power pooling, and coordinated development of power resources. In 1925 a total of 560 companies were involved in mergers, of which 153 were absorbing companies and 407 were acquired companies.[1] Many of these mergers involved hydroelectric plants. Some persons view this trend as a menace to public welfare, an attempt to subject the industrial and domestic consumers of electrical energy to the tyranny of a power monopoly. The growth of the holding company in connection with these mergers and the interlocking directorates behind these various power groups are cited as evidences pointing toward the development of

[1] *Electrical World*, January 2, 1926, Vol. 87, No. 1, p 24

a power monopoly. By others, this trend toward centralization is regarded as a step toward more economical management, more effective use of power equipment, more efficient utilization of fuel, accompanied by a reduction in rates for the benefit of the consumer. Whatever may be the true situation, it behooves the public to take an active interest in the effects of power development and power distribution upon social and economic conditions.

The stake of the public is a cheap and reliable supply of power, widely distributed and available to all. The domestic consumer is interested in a rate which permits him to have many of the electric conveniences in the home at a cost within his reach. The manufacturer of commodities is just as vitally interested as is the domestic consumer, for the price of power affects his production costs. The purchaser of the manufacturer's goods has identical interests, for, under the competitive system, the savings in power costs by the manufacturer may be passed on to the consumer.

The immediate interests of the present must be accompanied by an interest in the welfare of succeeding generations. The importance of power in supplying our many material wants and comforts is so great that the present generation must not misuse and waste needlessly the sources of energy. Our supplies of coal, vast though they may be, are, nevertheless, wasting assets, and common sense dictates that they be used as economically as possible. Water power, which is self-replacing, can be the means of saving thousands of tons of coal annually, and it is to the public interest, not only to harness water power, but to harness entire streams or drainage basins according to plans which will derive from them the utmost of their power potentialities. A single power plant located on a stream without regard to further utilization of the stream may be the means of destroying much of the available power. This can be avoided only by comprehensive plans for stream development. Such circumstances may mean a conflict between private interests

and public welfare, a conflict not altogether unknown in many phases of our industrial life. The social ideal to be sought in the utilization of water power resources can best be stated by repeating the words of Van Hise in the last chapter of his book on the *Conservation of Natural Resources,* namely "the greatest good to the greatest number —and that for the longest time."

The public policy which will most nearly accomplish this ideal may take any of three directions, namely, (1) unrestricted private development; (2) regulated private development; or, (3) public ownership. Possibly these policies may be developed side by side for different classes of water powers.

At present the opinion of this country, as expressed through state and Federal legislation, favors regulated private development. Public ownership with leasing has been attempted or proposed in a few instances, notably the Hydro-Electric Power Commission of Ontario, Canada, with less pretentious attempts by the Government of the United States at Muscle Shoals, of the city of San Francisco in its Hetch Hetchy project, and the proposals of Senator Johnson for the public development of the Colorado River, and of Governor Smith in the State of New York. Public regulation of electric utilities, including hydroelectric plants, has confined itself largely to the determination of rates to be charged and services to be rendered. A more extensive public control of private utilities, one which will include supervision of the financial policies, location and erection of plants, steam and hydro, and of transmission lines was proposed by Gifford Pinchot, while governor of Pennsylvania. This proposal, called Giant Power, contemplated a great pool into which power from all sources could be poured, and out of which power for all purposes could be taken. Although this plan, if adopted, would have been concerned primarily with steam power plants, its regulatory features paralleled so closely in many respects those of the Federal Water Power Act that it deserves a brief analysis.

THE GIANT POWER PLAN

This plan, submitted to the Pennsylvania legislature in May, 1923, contemplates the creation of a Giant Power Board with authority to issue permits to private companies to construct and operate large steam stations (300,000 kilowatts or more), to engage in coal mining and manufacture of coke, gas, and other by-products, to buy and sell electric current in wholesale quantities, to construct high tension transmission lines, gas pipe lines, oil pipe lines, and to engage in other incidental business. Under this plan, the public service business of the state would be segregated into three separate classes, namely, major generation, major transmission, and distribution, including minor transmission. No corporation would be allowed to do more than one of the three kinds of business. The major transmission systems were to be constituted common carriers with the duty of taking electric current of standard voltage and frequency from all public service generating stations and delivering it to all consignees which are public service distributing systems on terms subject to regulation by the Public Service Commission.

The aim of the Giant Power proposal was to lay a comprehensive plan for power generation and distribution throughout the state, to scrutinize carefully the rates charged and services rendered by the companies, and to supervise the financial policies of the generating, transmission, and distributing companies.

The scheme of mass production of electrical energy, to effect the greatest possible economy in the use of capital and raw materials, implies also the manufacture of various by-products and a coordination of power stations and transmission lines throughout the state. The manifold objectives of this plan, if carried to their ultimate conclusion, would be the creation of a large number of industrial activities over which the state exercised a more or less limited control. The objectives may be summarized as follows:

1. Large-sized steam generating stations, with capacities as a rule of not less than 650,000 horsepower in a given locality, to be—

2. Located at or near the mines—and supplying current to—

3. Trunk transmission lines reaching 220,000 volts.

4. An integrated system of supply and transmission and of distribution.

5. Full development of water powers.

6. The pretreatment of coal for the recovery of its by-products.

7. Trunk line railroad electrification.

8. Electric service for the rural population.

9. Material reductions in rates, especially to the smaller consumer and at least in proportion to the reduction in cost.

10. The public direction and supervision of the great new developments in the general interest.

The Giant Power Survey Board authorized by the Pennsylvania State Legislature in 1924 completed its work and submitted a report early in 1925. The succeeding legislature, however, failed to enact the necessary legislation to carry out the plan, and it died with the end of the Pinchot régime.[2]

THE HYDRO-ELECTRIC POWER COMMISSION OF ONTARIO

The Giant Power Plan, although far reaching in its regulatory proposals, did not depart from the principle of private ownership and operation of utilities. In fact, Governor Pinchot advanced the argument that the strict regulation of private enterprise in so important a human need as electrical energy was the best antidote for public ownership sentiment. Adherence to the principle of private ownership appears to be less strong in Canada, where, as early as 1903, a movement was begun which culminated in the first major public ownership experiment in North America.

The first distribution of electrical energy by the Hydro-

[2] Giant Power. *Report of the Giant Power Survey Board to the General Assembly*, Pennsylvania, February, 1925.

Electric Power Commission of Ontario was in 1910, when it supplied 10 urban municipalities with an initial load somewhat less than 1,000 horsepower. In 1924 the commission was operating 750,000 horsepower and, in addition, had under construction the Queenston-Chippewa development on the Niagara River with an ultimate capacity of 600,000 horsepower. The total capacities in horsepower of the several plants owned by the commission are here summarized.

Queenston	350,000 horsepower
Ontario Power Co. plant	185,000 horsepower
Toronto Power Co. plant	125,000 horsepower
Total	660,000 horsepower

In addition to the plants it owns, the commission operates several others, bringing the aggregate of installed power under its control up to approximately 1,000,000 horsepower.

The largest system, the Niagara, supplies practically the whole of southwestern Ontario, from Toronto to Windsor, with power from Niagara. The other systems are supplied from plants either purchased or built by the commission on the Severn, Beaver, Muskoka, Nipissing, Nipigon, and Mississippi rivers, and seven plants on the Trent Canal system.

ORIGIN OF THE HYDRO-ELECTRIC POWER COMMISSION

In the year 1906, at the behest of a number of Ontario manufacturers seeking a cheaper source of electric power, the Provincial Government provided by special act the Hydro-Electric Power Commission of Ontario. The commission was authorized to act as trustee and agent for such municipalities in the province as desired to cooperate for the securing of electrical energy. It is not surprising that so important a proposal as power production by a public agency met with bitter opposition from the press and the politicians.

ORGANIZATION AND POWERS OF THE COMMISSION

The commission consists of three persons appointed by the Lieutenant-Governor in Council, two of whom may be, and one of whom shall be, a member of the Executive Council. "The Commission may report to the Council as to what property and sources of power should in their opinion be acquired for the purpose of the Act, and, when so authorized by the Council, may purchase, lease, or otherwise acquire lands, water powers or works to be used for producing power from water or from any other source and transmitting and delivering same. The Commission may similarly be authorized to contract for the purchase of power and for its sale to municipalities and others. The money required for these operations is raised by means of government loans approved by the legislature, and by bonds issued by the Commission and guaranteed by the province."[3]

The commission exercises both administrative and constructive functions, and has evolved a well-defined policy for the transmission and the distribution of electrical power under municipal ownership. The fundamental basis of the undertaking is a partnership of municipalities formed to obtain electrical energy for their citizens *at cost*. "Cost," so far as "Hydro" power is concerned, includes all charges arising from the generation, transmission, and delivery of power to the municipalities. These charges include for each municipality its proper share of the interest and sinking fund on the cost of lands, stations, and equipment required for supplying power, as well as a proportionate part of administration, operation, maintenance, taxes, renewal and contingencies, reserves, and of all other costs entering into the business of supplying electricity. The first chairman of the commission was Sir Adam Beck, under whose able direction the commission was organized and, within the space of four years, was supplying 14 cities with electric power.

[3] J B Challies, "Water Power Resources of Canada," *Transactions of the World Power Conference*, 1924, Vol I, p. 222.

THE FINANCIAL STRUCTURE OF THE HYDRO-ELECTRIC POWER COMMISSION

The framework of the financial structure of the Hydro-Electric systems is summarized in a statement by the late Sir Adam Beck, chairman of the commission, as follows:[4]

1. The generation and transmission of power on a wholesale scale is dealt with by a commission which, although appointed by the government of the province, acts independently in the capacity of trustee and agent for the partnership of municipalities.

2. The local distribution of electrical energy within the borders of a municipality is, in general, under the administration of public utilities commission appointed under the provisions of the Public Utility Act.

3. Capital required for the plant for the generation and transmission of power is provided by the government upon receipt of formal requisition from the commission. Contracts are entered into between the commission and the municipalities under the terms of which the municipalities undertake to repay in 30 years the moneys thus loaned by the government.

4. The local distribution system is financed by the issue of municipal debentures.

5. The "Trustee" commission supplies power to the municipalities, charging each municipality the actual cost.

6. Each municipality sells electrical energy to its local consumers at rates and under conditions approved by the commission. The rates charged to its customers by a municipality are sufficient to take care both of the cost of distribution within the municipality and of the estimated cost of power to be paid to the commission by the municipality.

ACTIVITIES OF THE HYDRO-ELECTRIC POWER COMMISSION

The growth of the operations of the commission has been remarkable. From supplying 12 municipalities in 1910 from a single transmission system its operations have expanded until in 1924, from 11 distinct systems, the commission is supplying under contract 280 municipalities and in

[4] *Survey Graphic*, March 1, 1924, p. 586.

addition numerous large corporations. Since commencing operations the commission and municipalities have purchased 21 water power sites, 30 generating plants, and 60 distribution systems. The various systems owned or operated by the commission for the participating municipalities are as follows: Niagara, Severn, Wasdell, St. Lawrence, Ottawa, Thunder Bay, Eugenia, Muskoka, Northern Ontario (Nipissing), Central Ontario, and Rideau systems.

The commission now supplies under contract directly and indirectly to 280 urban municipalities, including 23 cities, 84 towns, and 148 villages, and in addition is supplying approximately 15,000 suburban consumers and over 5,000 farms in 132 townships.

Table 22 indicates the growth in demand for hydroelectrical energy on the commission's systems.

TABLE 22

GROWTH IN DEMAND FOR HYDRO-ELECTRIC ENERGY*

Year	Number of Customers			Total Loads for October	
	Urban Municipalities	Townships	Total Consumers	Ontario Only (H p)	Ontario plus Exported Power (H.p.)
1910	10	..		750	. ....
1911	26	.	.	15,214	.. .
1912	36		34,967	31,019	.. .
1913	51	7	65,689	45,502	....
1914	82	12	96,844	76,977	.
1915	112	18	120,828	103,959	.
1916	166	25	148,732	167,661	. .
1917	179	34	170,916	266,214	333,390
1918	193	41	183,987	253,562	316,592
1919	208	42	216,086	262,281	328,175
1920	217	43	244,388	283,372	355,798
1921	236	44	265,547	305,247	375,010
1922	247	81	335,000	490,487	572,550
1923	249	116	400,000	580,392	685,486
1924	256	124	415,000	655,588	780,789

* *Statement and Engineering Report by the Hydro-Electric Power Commission of Ontario Submitted to the International Joint Commission Respecting the Proposal to Develop the St. Lawrence River*, 1925, p 6

CRITICISMS OF THE HYDRO-ELECTRIC POWER COMMISSION

The commission has not carried out its extensive program without encountering opposition and criticism from both Canadian and American sources. The principal criticism in Canada came from the short-lived Drury United Farmer government in 1919. Under the instigation of this government a commission headed by W. D. Gregory was appointed to investigate the policies and administration of the "Hydro." The investigation continued two years and cost more than a half million dollars. It embodied more than 1000 volumes of testimony, in view of which fact it was never printed, but a summary was prepared by Premier Ferguson of Ontario, the principal points of which are listed below.

> The principle of public ownership of water powers of the province and their developments by the people for the people is, in our opinion, fundamentally sound and should be maintained at all hazards in its full integrity.
>
> 2. The engineering department of the commission is made up of men of high professional qualifications as engineers, and as such they are serving the commission zealously and efficiently. The various plants of the commission are exceptionally well operated by them.
>
> 3. That the method of accounting adopted by the commission is financially sound there is not the slightest doubt.
>
> 4. Some matters of administration policy were criticized in the Gregory report, principally:
>
> *a*) There has been too great a tendency on the part of the commission to defer the time for refunding the obligations.
>
> *b*) There is a tendency to underestimate costs of construction.
>
> *c*) A list of criticisms dealing with the administration of specific projects also were added.

The late Sir Adam Beck, chairman of the commission from its inception in 1906 until his death in 1924, replied to the Gregory Commission's report in a vigorous rejoinder on May 15, 1924, stating that the report is "permeated by

incorrect and misleading statements" particularly concerning the relation that certain conclusions reached and comments made by the Gregory report bear to the evidence submitted at the hearings.

The principal criticisms emanating from American sources are those of the Murray-Flood report made for the National Electric Light Association and a later report by S. S. Wyer, issued as a publication of the Smithsonian Institution.[5]

The Wyer report charges that:

1. A lower rate for electric service in Ontario than elsewhere is aided because the "Hydro" property is tax exempt.

2. Rural line extensions are subsidized to the extent of 50% of their cost by payments out of the provincial treasury.

3. The provincial treasury pays the expenses of engineering assistance, preparing estimates, making general surveys, and rendering electrical inspection service to various municipalities.

4. The accumulation of a sinking fund to pay off the bonds is being deferred from 5 to 15 years, thus placing on a future group of customers the burden of return of money used by present consumers.

5. The largest group of consumers, the domestic group, receives electric service at a rate lower than the cost of distribution, and this loss must be borne by the industrial consumers.

Sir Adam Beck, in his reply to the criticisms of Wyer, charges a misinterpretation of facts and an attempt to discredit public ownership. He categorically denies the assertions advanced by Wyer that the Ontario utilities are not taxed and that domestic consumers are supplied at rates below cost, stating that the commission pays annually taxes amounting to hundreds of thousands of dollars and that costs are analyzed in detail each year to make sure that no class of customers is charged either more or less than the actual cost of the service it receives.

In regard to the second and third items, Sir Adam says

[5] "Niagara Falls: Its Power Possibilities and Preservation," *The Smithsonian Institution's Study of Natural Resources*, Publication 2820, January 15, 1925.

that "there is no more justification for assuming that these expenses should be charged as part of the cost of supplying power to the Commission's customers in Ontario than there would be for assuming that expenses similarly incurred by, say, the U. S. Bureau of Standards or by the U. S. Geological Survey should be charged against the operation of the power companies of the United States."[6]

The shortages in the sinking fund exist, according to Beck, only in Mr. Wyer's imagination. He has assumed that "the Commission's large power developments were to commence repayment of their capital cost out of revenue some years before they were sufficiently advanced in construction to earn any revenue at all."[7]

Whatever may be the truth of the situation in regard to the costs of operation and rates for services, this great experiment in public ownership deserves careful study and observation by those interested in public utility economics. The criticism by Wyer, and the denial by Sir Adam Beck, that the domestic consumer is served at less than cost especially deserves study. If Beck's contention is true, that the costs of distribution are covered by the rates charged, then, indeed, the American domestic consumer has grounds for complaint and criticism of the policies of privately owned corporations. To him, it means that he is paying a rate from which the industrial consumers of the same station, or the public utility corporation itself, are receiving disproportionate benefits. If, on the other hand, Wyer's contention is sustained, the temporary advantages of the domestic consumers may ultimately react against the industrial opportunities of the Canadian manufacturers and the prosperity of the community as a whole. The cost of producing electricity at Niagara Falls on so large a scale as is done by the Hydro-Electric Power Commission differs to such an extent from the costs of energy from steam stations or hydroelectric plants elsewhere, that a comparison of

[6] *Electrical World*, Vol. 85, No 7, February 14, 1925, p 367.
[7] *Ibid.*

rates with other localities is not a sufficient basis for rendering judgment. The real results of this experiment in public ownership will become apparent only after considerable time has elapsed.[8]

MUSCLE SHOALS

The waging of the World War not only placed a heavy demand upon the manufacturing industries and transportation facilities of the United States, but also forced the government into activities which normally are undertaken by private initiative only. One of the vital necessities for the defense of a country or for the successful prosecution of a war is a supply of fixed nitrogen—the basis of modern explosives. And because of the fact that hitherto this country was in the precarious position of depending largely upon Chilean nitrates for this essential material, the War Department took steps to establish a domestic source of fixed nitrogen. The plan involved the construction of an electric generating station and the necessary chemical plants for fixing atmospheric nitrogen into ammonium salts and nitrates. The government-owned plant at Muscle Shoals, therefore, is a war measure.

The site at Muscle Shoals was selected because the necessary amount of hydraulic power was available, and also, the location was well within the "safety zone" established by the War Department. The original purpose, as stated in section 124 of the National Defense Act of 1916, was to provide nitrates for explosives. Accordingly, in 1917, two sites of land were purchased near Sheffield, Alabama, on each of which was erected a nitrate plant.

Proposed Development. In order to carry out this purpose the following developments were proposed. Three dams were to be built for the development of power and

[8] An excellent discussion of water power development under public and under private ownership is found in two articles by Harold I Patton, "Hydro-Electric Power Policies in Ontario and Quebec," *Journal of Land and Public Utility Economics,* Vol 3, No. 2, pp 132-144, and No. 3, pp. 225-240, May and August, 1927

for the improvement of navigation on the Tennessee River No power was to be developed at Dam No. 1, this merely serving to improve navigation. The principal source of power was to be at Dam No. 2 (known also as Wilson Dam).

Dam No. 2 is located 2½ miles upstream from Florence, Alabama. The total length of the dam is some 4,500 feet, and its total height from the river bed to the top of the pool elevation is 97 feet. It is provided with two locks in tandem—that is, one below the other—each 300 feet long and 60 feet wide. This dam forms a slack water pool about 18 miles long, backing the water up to Dam No. 3. The power station, when fully installed, will contain a wheel capacity of 612,000 horsepower.

Dam No. 3, which is not yet authorized, is to be built about 18 miles upstream from Dam No. 2 and will have an installed capacity of about 250,000 horsepower. This dam will be about 40 feet high and will be provided with one lock of 40 feet lift. It will form a slack water pool about 35 miles long, reaching practically to Decatur, Alabama. The construction of this dam immediately upon the completion of Dam No. 2 was strongly urged by General Taylor, in testifying before the Senate Committee in 1924, on the grounds that much expense would be saved by keeping the organization building No. 2 intact, and also because it would serve to regulate the flow of the Tennessee River.

The cost of the two dams complete with power equipment installed is estimated at $76,000,000, of which $51,000,000 is assigned to Wilson Dam and the remainder to Dam No. 3.[9]

The operating and maintenance costs and interest charges (interest charges do not include interest on any deferred interest payment) were estimated by Major Burns as follows:[10]

[9] "Muscle Shoals," *Hearings before the Committee on Agriculture and Forestry*, U S Senate, 68th Congress, First Session, 1924, p. 1450.

[10] *Ibid.*, p. 1469.

DAM NO 2

Plant operation expense, at $1 per installed horsepower	$ 624,000
Depreciation on equipment, $11,000,000 at 3½%	385,000
Depreciation on structure, $40,000,000 at ½%	200,000
Total	$1,209,000
Interest on $51,000,000 at 4%	2,040,000
Total	$3,249,000

DAM NO. 3

Plant operation expense at $1 per installed horsepower	$ 240,000
Depreciation on equipment, $8,000,000 at 3½%	288,000
Depreciation on structure, $17,000,000 at ½%	85,000
Total	$ 613,000
Interest on $25,000,000 at 4%	1,000,000
Total	$1,613,000

The nitrate plants.[11] The United States Nitrate Plant No. 1, designed to produce 22,000 tons of grained ammonium nitrate per year, is located on a site between the town of Sheffield, Alabama, and the Tennessee River. It occupies 1,900 acres of land and includes the following equipment: the water gas plant, the ammonia plant, the ammonia absorber house, the ammonium nitrate plant, power house, and auxiliaries.

Nitrate Plant No. 2 is located near the towns of Sheffield, Florence, and Tuscumbia. It is designed for the manufacture of calcium carbide, calcium cyanamid, ammonia gas, and nitric acid out of which ammonium nitrate is made.

In addition to the dam and nitrate plants, the properties at Muscle Shoals also include the Waco Quarry, constructed for the purpose of supplying limestone for the operations of the nitrate plant.

The cost of the entire equipment is here summarized:[12]

[11] For a detailed description of the dams and nitrate plants, see Report No 2041, *Fixation and Utilization of Nitrogen,* Nitrate Division, Ordnance Office, War Department, 1924.

[12] "Muscle Shoals," *Hearings before the Committee on Agriculture and Forestry,* U. S. Senate, 68th Congress, First Session, 1924, p 1450.

Item	Cost
Wilson Dam (No 2)	$ 51,000,000
Dam No. 1	1,600,000*
Dam No 3.	25,000,000*
Nitrate Plant No. 1	13,000,000
Nitrate Plant No 2	66,500,000
Waco Quarry	1,300,000
Total	$158,400,000

* Not yet authorized.

IMPORTANCE OF MUSCLE SHOALS AS A SOURCE OF POWER

Inasmuch as the original purpose for which the power plant and other equipment was erected has now disappeared, the disposal of Muscle Shoals has been almost constantly before the public notice and, at present writing, is still in about the same status that it was at the close of the war. Political expediency, division of opinions, and an exaggerated public opinion of its importance and value have contributed to the delay in effecting a permanent plan of disposal. Before discussing the problem of disposal of the plant, a brief review of its importance as a source of power is essential. Table 23 shows both the primary, or continuous, power obtainable, as well as the power available, at the two dams, for part of the year.

TABLE 23

POWER AVAILABLE AT MUSCLE SHOALS*

Class of Power	Horse-power	Kilo-watts	Kilowatt Hours per Year 100%	80%	60%
Wilson Dam					
Primary	87,300	65,100	570,269,800	456,215,800	341,161,900
Secondary	350,700	261,517	1,332,830,400	1,066,264,300	799,698,300
Dam No 3					
Primary	34,000	25,385	222,372,000	177,897,800	133,423,400
Secondary	145,500	108,468	564,475,000	451,579,900	338,684,300
Total					
Primary	121,300	90,485	792,641,800	634,113,600	475,585,300
Secondary	496,200	369,985	1,897,305,400	1,517,774,200	1,138,383,200
Total	617,500	460,470	2,689,947,200	2,151,957,800	1,613,968,500

* "Muscle Shoals," *Hearings before the Committee on Agriculture and Forestry*, U S. Senate, 68th Congress, First Session, 1924, p. 1452.

A fair estimate of the value of this power can be reached by comparison with the electric power output of the neighboring states. For this purpose Tennessee and Alabama are selected since these states will probably absorb the bulk of the power of Muscle Shoals. In Table 24 is given the kilowatt hour output of central stations of these states for the years 1921 to 1927, inclusive.

TABLE 24

KILOWATT HOUR OUTPUT OF CENTRAL STATIONS IN ALABAMA AND TENNESSEE*

Year	Tennessee (000 *omitted*)	Alabama (000 *omitted*)	Total (000 *omitted*)	Percentage Increase
1921	489,969	474,390	964,359	
1922	514,494	664,404	1,176,898	22
1923	649,484	823,216	1,472,700	25
1924	694,073	890,087	1,584,160	7
1925	874,973	1,169,101	2,044,074	29
1926	894,015	1,582,717	2,476,732	20
1927	1,030,000	1,822,000	2,852,000	15

* *Electrical World*, Vol 91, No 1, January 7, 1928, p. 20.

The continuous kilowatt hour output of Wilson Dam, using the minimum figure of 87,000 installed continuous horsepower, is:

570,269,800 at 100% load factor;
341,161,900 at 60% load factor.

The latter figure, which is probably near the actual operating load factor of central stations, is only 16.6% of the output of these states in 1925 and, moreover, is about equal to the annual increase in output over a period of five years. Much of the secondary power available can, however, be converted into primary power by the erection of steam stand-by stations or by the construction of storage dams in the upper Tennessee River to equalize the flow. The present rate of increase in power consumption, if continued in the future, can easily absorb the primary power of the two dams as soon as they are completed. Further increases in

power demands could be provided, most economically, by the construction of storage dams upstream, or by the erection of steam auxiliaries, or by a combination of both plans. While taking care of the immediate power needs, the present development also offers an opportunity to work out a program for the effective and complete development of the Tennessee drainage basin.

COST OF POWER

On a basis of valuing the present secondary power at half the value of the primary power, assuming that all the power would be utilized through pondage, interconnection, and so forth, the cost of production at the dams, including interest at 4%, will be:

Dam	Primary	Secondary
No. 2	2 6 mills	1 3 mills
No. 3	3 2 mills	1 6 mills

Assuming only 80% of the power of more than four months' duration were used, on the same basis of calculation the costs would be as follows:

Dam	Primary	Secondary
No. 2	3 25 mills	1 60 mills
No. 3	4 00 mills	2 00 mills

The figures given above are, of course, estimates and not based upon actual operating data, but they are believed to be reasonably accurate.[18]

PRESENT PROBLEM IN THE DISPOSAL OF MUSCLE SHOALS

The close of the World War found the power plant at Muscle Shoals still uncompleted. The nitrate and ammonia

[18] "Muscle Shoals," *Hearings before the Committee on Agriculture and Forestry*, U. S Senate, 68th Congress, First Session, 1924, p. 1471

plants were only a partial success and, except for test purposes, were never operated. Moreover, the rapid progress in the art of nitrogen fixation since the war has rendered these plants obsolete and costly in comparison with newer methods of manufacture. Very likely, the near future will see a private development in the air-nitrogen industry on a scale sufficient to remove any danger of shortage in a war emergency. This leaves a situation whereby the government is in possession of a large hydroelectric plant without any definite plan of operation or disposal. In 1924 several bids for the plant were received by the Secretary of War and referred to Congress. Action on all of these offers failed mainly because of the inability of Congress to agree upon a policy. One group sought to retain government control and operation. Another group wanted to dispose of the plant to private interests but could not agree among themselves as to who should have it. Although there were four bidders[14] seeking the property or part of it, the two principal contenders were Henry Ford and the Associated Power Companies of the South, that is, Tennessee Electric Power Company, Memphis Power and Light Company, and the Alabama Power Company. An interesting feature of the various proposals was the clause providing for the manufacture of fertilizers. The prospect of cheap fertilizers to be manufactured at Muscle Shoals held considerable interest to the farmers of the South, and very probably the bidders considered it necessary to insert a fertilizer clause as a bait to aid them in securing control of the power supply. As a matter of fact, the testimony by chemists and others familiar with the fertilizer industry before the Senate Committee indicated that an actual reduction in the cost of fertilizers was a remote possibility. The clause in the Ford offer was particularly ingenious in this regard. He proposed to manu-

[14] Associated Power Companies of the South, Ford, Hooker-Atterbury-White, and Union Carbide Company. For a detailed statement of the various proposals, see the *"Muscle Shoals," Hearings before the Committee on Agriculture and Forestry*, 1924.

facture fertilizers at a profit not to exceed 8% "of the fair actual annual cost of production thereof." Now it is quite likely that the manufacture of fixed nitrogen, using the electrolytic process of obtaining the needed hydrogen, could not be accomplished at a price insuring an 8% profit which could compete with Chilean nitrates or by-product ammonia. In this event Ford would possibly be released from the fertilizer requirements of his agreement and could then use the power for other purposes.

The more objectionable features of the Ford offer, however, lay in the fact that his proposal, in two important features, was contrary to the provisions of the Federal Water Power Act of 1920. First, he asked for a lease for 100 years, whereas the Act of 1920 limits all leases to 50 years, and secondly, he made no provision for the regulation of rates by a public service commission. To grant these requests would have set up a very dangerous precedent which, if granted to applicants for power sites elsewhere, would virtually nullify the Water Power Act.

The ostensible purpose of the nitrogen-fixing clauses in the offers of each of the four bidders was to provide a domestic source of fixed nitrogen for use of the army and navy in time of war, and to release the farmers from the domination of the Chilean nitrate producers in times of peace. Were these provisions necessary, or were they merely a tempting bait to secure favorable consideration of the respective offers? This can be answered only by an examination of the present nitrogen situation in the United States.

PRODUCTION AND IMPORTATION OF NITROGEN INTO THE UNITED STATES

The production and importation of nitrogen into the United States is shown in Figure 24 and in Table 25. The imports of 1918 and 1920 are due, of course, to the war demands. It is worthy of mention that the percentage of ammonium sulphate is increasing. This is due to the rapid

expansion of by-product coke ovens during the war period and also to the fact that the fertilizer manufacturers are overcoming the prejudice against ammonium sulphate as a fertilizer ingredient and are using it whenever the price of this material falls below that of Chilean nitrate. To offset ammonium sulphate competition, however, the Chilean Government in 1928 announced that it will indemnify Chilean nitrate producers who find it necessary to reduce prices in a competitive market.

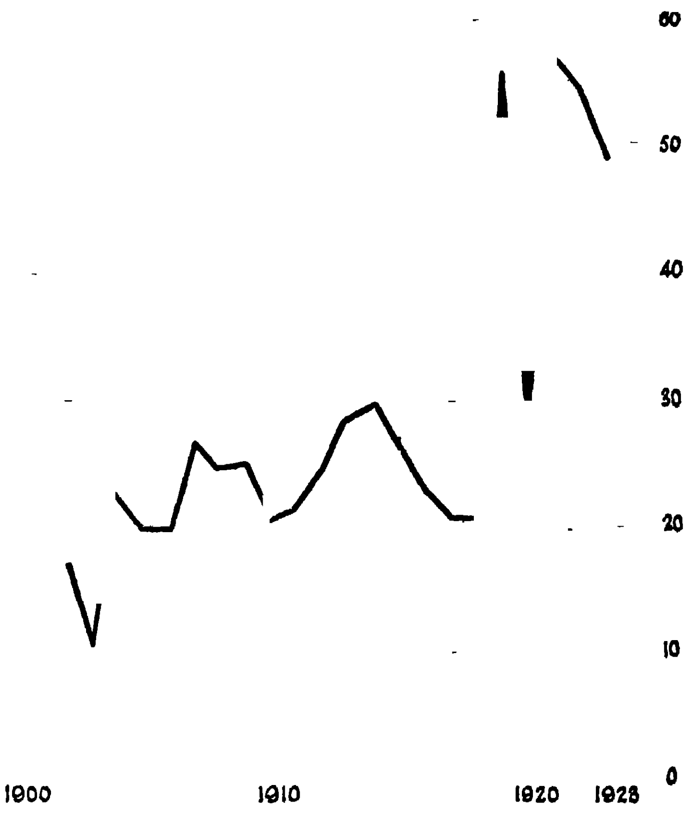

Figure 24: Percentage of nitrogen produced or imported into the United States as ammonium sulphate.

TABLE 25

PRODUCTION AND IMPORTATION OF NITROGEN*

Year	Nitrogen in Ammonia from By-Product Coke Ovens	Nitrogen Imported in Chili Nitrates	Total	Percentage of Nitrogen from Ammonium Salts
1900	. ....	38,600	38,600	.. .
1901	. . ..	33,000	33,000	.. .
1902	7,350	35,000	42,350	17 4
1903	4,700	40,000	44,700	10 5
1904	11,400	39,800	51,200	22 2
1905	13,620	56,000	69,620	19 6
1906	15,900	65,000	80,900	19 7
1907	21,050	63,800	75,850	26 9
1908	17,680	54,100	71,780	24 5
1909	24,400	74,000	98,400	24 8
1910	23,600	92,500	116,100	20 3
1911	25,500	95,200	120,700	21 1
1912	30,200	94,000	124,200	24 3
1913	40,500	102,000	142,700	28 4
1914	39,600	94,500	134,100	29 5
1915	47,800	135,000	182,800	26 2
1916	61,300	213,000	274,300	22 3
1917	69,000	270,000	339,000	20 3
1918	80,400	315,000	395,400	20 3
1919	87,000	71,200	158,200	55 0
1920	167,500	231,000	398,500	42 0
1921	76,000	58,000	134,000	56.8
1922	110,000	91,500	201,500	54 5
1923	131,000	138,000	269,000	48 7

* Trade Information Bulletin 226, *Nitrogen Survey*, Part II, "General Review of the Nitrogen Situation in the United States," Bureau of Foreign and Domestic Commerce, 1924.

ATMOSPHERIC NITROGEN

The production of atmospheric nitrogen has not made much headway in this country. The plant of the American Cyanamid Company of Niagara Falls remains the chief producer of air nitrogen in America. Its capacity is about 13,000 tons of fixed nitrogen annually.

NITROGEN NEEDS OF THE UNITED STATES

The nitrogen needs of the country may be divided into three groups; namely, agricultural, military, and industrial.

Agricultural needs. H. A. Curtis, chief of the Nitrogen Division of the Bureau of Foreign and Domestic Commerce, has prepared the balance sheet shown in Table 26 for the nitrogen in the soil.

TABLE 26

BALANCE SHEET FOR NITROGEN IN THE SOIL*

	Short Tons
Annual loss, 60 pounds per acre, 300,000,000 acres	9,000,000
Gain:	
From manure of domestic animals	1,750,000
Supplied by legumes	1,750,000
Atmospheric precipitation	750,000
Non-symbiotic bacteria	1,000,000
Total	5,250,000
Added in fertilizer	200,000
Net Annual Loss	3,550,000

* Trade Information Bulletin 226, *Nitrogen Survey*, Part II, "General Review of the Nitrogen Situation in the United States," Bureau of Foreign and Domestic Commerce, 1924.

NOTE: This table is taken from data proposed by Dr. J G Lipman, director of the New Jersey Experiment Station, and published in the *Journal of the American Society of Agronomy*, Vol. 2, No. 9, December, 1919. See this article for basis of estimates

This table shows that the soil nitrogen is not being replaced as fast as it is used. This does not necessarily mean that our present methods of agriculture are exploitative, but it does mean that as the demand for food increases with a growing population, it will become more and more profitable for the farmer to purchase nitrogenous fertilizers for increasing the acre yields. Eventually, he will be obliged to follow the European example of more intensive fertilization.

Military requirements. The nitrogen requirements for military purposes are small in time of peace, not exceeding 2,000 tons of fixed nitrogen annually. The war time requirements are, of course, large and uncertain. The estimated nitrogen needs of the last war amounted to about 12,000 tons in the twenty-fourth month of the war. This would be close to 150,000 tons a year, an amount nearly equal to that used in the fertilizer industry.

Industrial needs. The nitrogen requirements of industry are about 75,000 tons annually calculated as common sulphate.

SUMMARY OF NITROGEN NEEDS

It is evident that with the increase in the demand for food, together with the depletion of nitrogen reserves in the soil, the nitrogen needs of the agricultural industry will far exceed the present consumption as shown below.

Present fertilizer application..........	200,000 tons
Total theoretical needs..............	3,550,000 tons

This shows that to maintain the present nitrogen reserve 18 times more fertilizers are required than are now used. Obviously this amount will not be reached, or even approached, for decades to come. It does point to a time, however, when the business of supplying fixed nitrogen by importation from Chile, by recovery from coal, and by the fixation of atmospheric nitrogen will become an important one. The question then arises: Shall the Government of the United States authorize the establishment of a nitrogen-fixing plant at Muscle Shoals? The following suggestions may be given.

Plant No. 1, designed to produce ammonia, was unsuccessful, and the synthetic ammonia plant will have to be redesigned before it can be made to work. The parts of Plant No. 1 which were designed to convert ammonia into nitric acid and ammonium nitrate are successful, and these plants could be made to turn out 62 tons of ammonium nitrate daily with aqua ammonia obtained from the Alabama by-product coke ovens.[15]

Plant No. 2 could turn out 220,000 tons of ammonium sulphate annually, which would be equivalent to 40,000 tons of fixed nitrogen. "Operation of Plant No. 2 for products of ammonium sulphate would tend to lower the prices

[15] Bureau of Foreign and Domestic Commerce, Trade Information Bulletin No. 226.

of sulphate a little, but the effect of this on the fertilizer industry would be small. The whole proposition concerning Plant No. 2 comes down to the fact that the plant as it stands today cannot be used to effect any immediate result of large consequence in the fertilizer situation."[16]

The next question that arises is: Shall larger nitrogen plants be built at Muscle Shoals to supply fertilizer materials that will be needed in the future? The answer to this depends upon the possibilities of increasing the fixed nitrogen supply from other sources, principally coal and atmospheric nitrogen. With reference to the supply of nitrogen from coal, the estimates given in Table 27 have been made by Curtis.[17]

TABLE 27

ESTIMATED PRODUCTION OF NITROGEN FROM COAL IN 1933

(Expressed in tons of nitrogen)

Present production at by-product coke ovens	120,000
Increase from substitution of by-product coke for beehive coke	40,000
Increase because of increasing iron and steel demand	25,000
Increase from substitution of coke-oven gas for present carburetted water gas	10,000
Increase from substitution of coke-oven gas for natural gas	20,000
Increase because of new demands for city gas and coke for domestic and gas-making use	25,000
Total from coke ovens	240,000
Estimated present production at coal-gas works and from other sources	10,000
Total ammonia nitrogen excluding any increases in nitrogen fixed from the air	250,000
Equivalent in ammonium sulphate	1,250,000

This amount, together with the importation of Chile nitrates, is ample for immediate fertilizer requirements.

THE FUTURE OF ATMOSPHERIC NITROGEN

It appears quite probable that the fixation of atmospheric nitrogen is still in the experimental state and that further

[16] *Ibid.*, p. 44.

[17] *Ibid*, p. 27.

improvements in processes are likely to occur which will render the present methods obsolete and too expensive. It would seem advisable to withhold the erection of nitrogen-fixing plants on a large scale as proposed at Muscle Shoals until technical knowledge has been advanced further. In this connection it is interesting to note an announcement concerning E. I. duPont de Nemours and Company.

A plant site for the manufacture of synthetic ammonia has been purchased at Clinchfield, Virginia, by Lazote, Inc. (a corporation organized by E. I. duPont de Nemours and Company). The new corporation, after careful study of the several known processes, has acquired the Claude synthetic ammonia process, which is superior to the German Haber process, and will install it in the plant to be built on this site.

Field work and construction operations will be started in the early spring, and it is expected to have it in operation by the end of the year (1925). Plans for the plant provide for a capacity of 25 tons of ammonia a day, and they are so drawn as to allow for substantial enlargement.

The site selected at Clinchfield is next to coal fields, which will supply the necessary power and raw material; investigations having shown that in the synthetic ammonia process coal or coke can be used more economically than water power in the production of the essential raw materials, it heretofore having been considered necessary to have cheap hydroelectric power for the operation of synthetic ammonia or fixed nitrogen processes.

The rapid development going on in the art of nitrogen fixation is further illustrated in a lengthy statement by Dr. F. G. Cottrell, of the Fixed Nitrogen Research Laboratory, before the Senate Committee on Agriculture and Forestry on May 23, 1924. The gist of his testimony is a description of the process of obtaining the hydrogen necessary for nitrogen fixation directly from coke instead of obtaining it by the electrolysis of water. Both the German and the French processes are described in detail, and a brief resume of the economic advantages of each is given.[18]

The nitrogen-fixing industry can be promoted more effec-

[18] For a detailed discussion of these processes, see the *Muscle Shoals Hearings*, pp. 1291-1294.

tively by erecting small plants such as the duPont plant mentioned above, and by further experimental work along the lines indicated by Dr. Cottrell, than by large undertakings using obsolete methods and possibly subsidized by the government.

There has been no attempt in the above discussion to touch upon the problems of the fertilizer industry. They are far too complex to be treated here. A few statements regarding the industry will show that the manufacture of fixed nitrogen on a large scale at Muscle Shoals is no solution for these problems.

1. In most American soils, phosphorus, not nitrogen, is the limiting element in plant growth; the development of the industry means a greater traffic in phosphates than in the other two or three elements.

2. There is a great need for the production of a more concentrated product than the present acid phosphate before the industry can expand into the Middle West.

3. Before such a concentrated product can be marketed, much experimental work both in the technical process of preparing the material and in plot tests to determine its effects on the soil must be done.

4. One such concentrated product, mono-ammonium sulphate, could be produced advantageously at Muscle Shoals, because of nearness of raw materials, if it could be sold on the market.

5. The agricultural industry, outside of the Cotton Belt, is not yet ready to take large amounts of fertilizer.

THE PUBLIC OWNERSHIP PROPOSAL

The public ownership and operation of the power equipment and chemical plants at Muscle Shoals was proposed in a bill introduced by Senator Norris, of Nebraska, chairman of the Committee on Agriculture and Forestry. This bill provided for the completion of the power plant and remodeling of the chemical plants by the Secretary of War, who would then turn over the properties to the Federal Chemical Corporation created by this bill. This corpora-

tion was to be directed by a board of three members appointed by the President with the concurrence of the Senate and should have power to:

1. Maintain laboratories and experimental plants for the purpose of conducting research in nitrogen fixation.
2. Manufacture fertilizers and the chemical parts of fertilizers.
3. Manufacture explosives as required by the army and navy.
4. Dispose of the surplus power on fair and equitable terms.

In brief, the measure proposes that the Government of the United States engage in the business of manufacturing and selling electrical energy and chemical fertilizers. The significance lies in the fact that it is a serious attempt to have the government enter a field hitherto occupied exclusively by private interests. This bill, together with the various bids from private corporations, died at the expiration of the 68th Congress, but, no doubt, will be revived when the debate on the disposal of Muscle Shoals is resumed.

OTHER PUBLIC DEVELOPMENTS

The power developments undertaken by the Federal Government, with the exception of Muscle Shoals, have been merely incidental to some other activity. It has, for example, developed power in connection with irrigation projects where surplus water has been available for the purpose, but these power developments have been of relatively small capacity and serve only the irrigated lands or the adjacent local communities.

There are a few state-owned and operated electric utilities in the United States. The chief examples are the power plants being constructed by New York State to develop power from the surplus water of the state-owned Barge Canal, and similar developments along the canalized Des Plaines and Illinois river, where surplus water in excess of navigation needs is available.

The most noteworthy examples of municipal power plants are the hydroelectric developments of the cities of Los Angeles and San Francisco, in California, and of Tacoma and Seattle, in Washington.

A proposed Federal development of major importance is that at Boulder Canyon in the Colorado River. This proposal is intimately related to the problems of irrigation, flood control, and water supply of the Southwest and has been treated in a previous chapter.

XI

FOREIGN WATER POWER NOTES

General survey. Canada. Europe—Italy, France, Norway, Switzerland, Sweden, Germany. Japan. Conclusions. Summary of potential and developed power.

THE developed water power of the world, according to estimates made by the United States Department of the Interior through the Geological Survey, was about 23,000,000 horsepower in 1920, 29,000,000 horsepower at the end of 1923, and 33,000,000 horsepower at the end of 1926, an increase of 43% in six years. About three-fourths of the increase for the last three years has been in the English-speaking section of North America. Europe made a brief spurt during and after the World War but has now slowed down appreciably in its construction of hydroelectric power plants. Canada is the only country that approaches the United States either in the size of constructed plants or in the rate at which development is taking place. Italy and Switzerland are still making considerable progress in building new plants, and Sweden and Norway have a slow, steady growth. France and Germany are depending more on steam plants. No recent figures are available for Japan, but it is presumed that plants already undertaken are gradually being completed.

CANADA[1]

The fortunate occurrence of about 60% of Canada's total water power in the highly industrial, but non-coal producing,

[1] Adapted from the report of the Department of Interior, Canada, *Dominion Water Power and Reclamation Service*, 1926, on the water power resources of Canada.

provinces of Ontario and Quebec, the close proximity of water powers to the mineral and pulpwood areas throughout the entire country, and the fact that nearly all the centers of population have water power within easy transmission distance are circumstances which, while of course altogether fortuitous, combine to provide a market for power in which the supply barely keeps pace with the demand. Indeed, this is one of the outstanding points of interest in present-day developments. Where a few years ago blocks of 10,000 to 20,000 horsepower would come on the market after an extended period of construction, now plants of 100,000 horsepower or more are brought into operation within the year.

The year 1925 witnessed the unprecedented increase in Canada's hydraulic installation of 718,984 horsepower, bringing the total installation for all purposes to the imposing total of 4,290,428 horsepower, and the year 1926 saw this increased to 4,556,000 horsepower. While actual construction in 1925 and 1926 was confined to only four of the provinces, British Columbia, Manitoba, Ontario, and Quebec, considerable activity preliminary to construction was evidenced in other provinces. That the limit of individual plant capacity has not been reached even by the great stations recently constructed is indicated by the inception of a plant on the Saguenay River of 800,000 horsepower ultimate capacity, while plans for an enterprise of almost equal ultimate capacity on the Bridge River in British Columbia involving the development of a series of sites are in course of preparation.

While complete information regarding Canada's great water power resources is not yet available, all existing stream flow and power data from federal, provincial, and private sources have been systematically collated, analyzed, and coordinated with the object of presenting a dependable estimate of available power based on uniform methods of computation and arrangement. The figures for available water power listed in Table 28 are based upon rapids, falls,

and power sites of which the actual existent drop of the head, possible of concentration, is definitely established or at least well authenicated. Many rapids and falls of greater or lesser power capacity are scattered on rivers and streams from coast to coast which are not as yet recorded, and which will become available for tabulation only as more detailed survey work is undertaken and completed. This is particularly true in the relatively unexplored northern districts. Nor is any consideration given to the power concentrations which are feasible on rivers and streams of gradual gradient, where economic heads may be created by the construction of power dams, excepting only at such points as definite studies have been carried out and the results made matters of record.

TABLE 28

AVAILABLE AND DEVELOPED WATER POWER IN CANADA*

Province	Available 24-Hour Power at 80% Efficiency: At Ordinary Minimum Flow (h.p.)	Available 24-Hour Power at 80% Efficiency: At Ordinary 6-Month Flow (h.p.)	Turbine Installation (h.p.)
British Columbia	1,931,142	5,103,460	414,702
Alberta	475,281	1,137,505	34,107
Saskatchewan	513,481	1,087,756	35
Manitoba	3,270,491	5,769,444	183,925
Ontario	4,950,300	6,808,190	1,784,842
Quebec	6,915,244	11,640,052	1,747,386
New Brunswick	50,406	120,807	44,631
Nova Scotia	20,751	128,264	65,327
Prince Edward Island	3,000	5,270	2,274
Yukon and Northwest Territories	125,220	275,250	13,199
Canada	18,255,316	32,075,998	4,290,428

*January 1, 1926.

A study of the uses to which the water power installation of Canada is put emphasizes the growing importance of central electric stations. The 4,290,428 horsepower at present installed throughout the Dominion is apportioned to

the following uses: 3,466,422 horsepower, or 80.8% of the total, in central electric stations for general distribution, for domestic, municipal, and commercial lighting and power purposes: 481,971 horsepower, or 11.2%, installed in pulp and paper mills. In addition, pulp and paper mills purchase about 275,000 horsepower from central electric stations, making a total of nearly 757,000 horsepower used in the manufacture of pulp and paper; 342,035 horsepower, or 8.0%, is installed in industries other than central electric stations and pulp and paper mills. The total installation for the Dominion averages 465 horsepower per 1,000 of population, a figure which places Canada among the leading countries of the world in per capita utilization of water power.

EUROPE

Nearly 90% of the hydroelectric power developed in Europe is found in the countries of Italy, France, Norway, Switzerland, Sweden, Germany, and Spain in the order named. The combined total for these countries is 10,500,000 horsepower, which is about equal to the developed power of the United States. The important features of the water power developments in the principal countries are given below.

Italy. The chief determining factors in the rapid hydroelectric development in Italy are the presence of many high mountainous regions, the abundant rainfall over the greater part of the country, and the lack of coal resources.

Out of an estimated potential supply of 3,800,000 horsepower,[2] about 60%, or 2,300,000 horsepower, has been installed at the end of 1926. More than half of this is located in the mountains surrounding the Po Valley. The unique feature of the Italian hydroelectric industry is the early development of transmission lines connecting the various plants. The necessity for this is found in the characteristics

[2] Mimeographed Release of the U. S. Geological Survey, December 19, 1927.

of the rivers. The hydroelectric plants of northern Italy are situated in the Alps, high mountains where the winter snows constitute an immense reservoir, yielding a relatively small flow of water in winter and great quantities in summer. In central and southern Italy, on the other hand, the mountains, being much lower, do not present the same phenomenon of accumulating water in the form of snow, consequently here the flow of water is small in the summer and large in the winter. This is corrected, to a certain extent, by the construction of artificial lakes, many of which are already in existence. The linking up of plants of various districts remains, however, the only possible means of satisfactorily counterbalancing the small winter flow in the north of Italy and the high flow in the central and southern portions, and vice versa. It may be said, in fact, that by means of a few copper wires a great hydraulic regularization of the main waterways is being carried out.

Another example of what may be called the regularization or compensation of the hydrological regimens of distant districts by means of copper wires is furnished by Calabria and Sicily in southern Italy. In Sicily the presence of water in summer has an enormous value for irrigation. Hence, it becomes advisable to store as much water as possible during the winter and work the hydroelectric plants possessing storage reservoirs almost exclusively during the summer, as the water is afterwards conveyed to the fields for irrigation. This necessitates an additional supply of electric energy for the winter. This will now be made possible by uniting the Sicilian plants to those of the Sila, in Calabria, which, on account of their great potentiality (more than a billion kilowatt hours) will be able to provide for all of the needs of southern Italy in respect to power.

In the absence of coal, previously noted, the dependence of Italian manufacturing industries in the Po Valley upon hydroelectric energy is obvious. In order to judge of the consequences which this agricultural use of hydroelectric energy is likely to have on the country's economy, it will be

sufficient to remember that in southern Italy there are more than two million acres of land requiring irrigation; land, at present of no value, can be given a capital value from 100 to 200 millions of Lg.

France. Conditions in France closely parallel those in Italy. Although coal supplies are far more abundant than in Italy, they are not sufficient for domestic needs, and water power has been harnessed wherever economy has permitted. The most rapid development occurred during the period of the World War. The occupation of northern France by the German army resulted in a loss to France of the principal coal fields. Under the pressure of this emergency, France inaugurated a water power policy which was to be further extended after the cessation of the war. The intensive wartime construction efforts resulted in a doubling of the installed hydroelectric capacity (from 638,010 horsepower in 1914 to 1,244,910 horsepower in 1918). The impetus given to the development of hydro electric power during the war continued until in 1926 a total of 2,268,000 was reached.[8] Since then the rate of construction of new plants has declined.

Concurrent with the expansion of the hydroelectric industry in France has been a tendency to a more unified use of drainage basins. This tendency is expressed in a law which provides that the officials empowered to pass upon applications for water power concessions shall consider each project as a unit in the development of the whole basin.

The efficient utilization of the resources of an entire drainage basin is aided by the use of interconnecting transmission lines among various basins. By this means the heavy summer rainfall in the Pyrenees and the Alps can be made to supply power to central France where the summer run-off is low, and vice versa. It is estimated that such interconnection, when completed, will increase the effective

[8] J. R. Cahill, *Report on the Economic and Industrial Condition in France,* 1925-26, Department of Overseas Trade, London, 1927, p. 200.
AUTHOR—PLEASE ADD 1 LINE.

capacity of the present and proposed plants by 400,000 horsepower.[4]

Norway. Norway is undoubtedly more favorably situated with regard to water power than any other nation of Europe. The potential power, as estimated by the Government of Norway, is about 12,000,000 horsepower, of which 1,900,000 is now developed. The distribution of the developed power in the different branches of industry for 1922 is given in Table 29, below.[5]

TABLE 29

DISTRIBUTION OF DEVELOPED POWER IN NORWAY, 1922

Wood pulp industry	220,000 h.p.
Electricity works	694,000 h.p.
Electrochemical and electrometallurgical industries	766,000 h p.
Other industries	140,000 h.p.
Total	1,820,000 h p.

An outstanding feature of the developed resources is the high percentage utilized in the electrochemical and electrometallurgical industries, perhaps indicating that, to a great extent, this kind of industry is going to be indigenous to this country.

Cost of Norwegian power. The main part of the power used by the wood pulp industries has been developed at about 250 kroner per horsepower, or about 25 kroner per horsepower year. An essential part of this power development took place before 1905. It is about this time that the development of power for the electrochemical industry began, especially the nitrogen industry, the carbide industry, ferro-alloys, and so forth. The development which took place during the years 1905-1915 for large industries was exceedingly cheap, and can for the most part be considered the cheapest development of water power which has ever

[4] MM. Duval et Lavauchey, *Revue Générale de l'Electricité*, March 24, 1923.

[5] *Transactions of the World Power Conference*, London, 1924, Vol. I, p. 1047.

taken place. During this time about 400,000 horsepower was developed at prices varying from 100 to about 150 kroner per horsepower, or 10 to 15 kroner per horsepower year—in other words, less than $5 per horsepower year. It is not expected, however, that further development of water power can take place except at a considerably higher cost.

Switzerland. The water power available in Switzerland is conservatively estimated at somewhat over two and a half million horsepower, of which 1,850,000 was developed in 1926. About half of the electrical energy is utilized for lighting, motive power, and heat appliances, with the electrochemical and electrometallurgical industries following next in importance. "At the end of 1922, about 95% of all the localities in Switzerland were connected to electric distribution systems. About 90% of all houses were fitted with electric light; about 95% to 98% of stationary motors were run by electricity; about 40% to 45% of the length of the railway tracks were electrified; and the use of electric energy was already widespread in industry, home, and agriculture."[6]

The hydrological conditions are somewhat unfavorable to the economical use of the water power resources. During the winter the rivers in Switzerland generally have a small quantity of water; during the summer, on the other hand, there is an abundance of water. Conversely, a much larger quantity of electricity is needed during the winter; there is, therefore, a surplus of energy during the summer and a deficiency during the winter. It is for these reasons that summer water is stored, if possible, in natural or artificial lakes in view of its utilization during the winter.

The rivers in Switzerland are, with a few exceptions, public property, and are as a rule operated by concessionaires.

Sweden. Practically all of Sweden's water power development has occurred in the southern, densely populated portion of the nation. Northern Sweden is sparsely settled,

[6] *Ibid*, p. 1380.

the population being chiefly concentrated on the banks of the great rivers, especially along the lower courses. The greater industries, sawmills and wood pulp and paper mills, are generally situated on the coast, since the timber can be floated down the rivers at low cost, and only rarely in the interior where the waterfalls are found. Therefore, few power distribution systems of any importance are found inland. The few inland industries usually obtain their power from greater or smaller isolated power stations, and the sawmills and pulp mills mostly utilize wood refuse as fuel for steam production.

Potential water power. Sweden's total water power resources cannot be estimated with any high degree of accuracy, until more complete surveys have been made. However, the total water power before regulation has been approximately estimated to be at least 10 millions of horsepower available during six months, or 6¾ millions of horsepower during nine months. However, the total available water power of Sweden cannot be economically utilized within any reasonably near future. The greatest sources of power are located in the northern districts of the country, while the greatest demand for power exists, and probably will ever exist, in the central and southern provinces. As long, therefore, as it is impossible to transmit power economically over such great distances, the figures stated above must be essentially reduced.

Germany. With regard to the extent and nature of her water power resources Germany is less favored than some of her neighbors as, for example, Switzerland or Scandinavia. It is only in the southernmost part of Germany, in the Black Forest, in the small portion of the Alps belonging to Germany, and in the areas crossed by rivers carrying water from these mountains, that favorable conditions exist for water power development.

The utilization of water power in Germany is under the control of the states. The regulations covering the exploitation of water power sites are far reaching and are intend-

ed to secure the maximum power yield of the stream. The more important provisions for the supervision and control of hydraulic powers are as follows:

1. The exploitation of water power must be sanctioned by the state. This sanction should be granted for a limited time only. After 50 to 70 years all such recently built water power stations should become government property without compensation. All plans and drawings must be submitted to and approved by the government supervisors.

2. Private builders of water power stations are granted the right to expropriate the necessary ground if the new enterprise wholly or partly serves public interests.

3. The intended development of a portion must fit into the scheme laid down for the whole river.

In addition to the above general principles, provision must be made for storage, for the safeguarding of agricultural land in the vicinity of works, for the protection of navigation on the rivers, and for the interconnection of plants with the view of increasing the effectiveness of the available water.

JAPAN

A survey of the water power resources of Japan completed in 1923 estimates the total available power at 6,415,-000 minimum flow, and 14,090,000 for six-months flow. A comparison of steam and hydroelectric power as shown by recent power installations (Table 30) discloses the preponderance of water power over steam.

TABLE 30

RECENT POWER DEVELOPMENTS IN JAPAN*

Year	Hydro	Steam	Total
1920	713,385	500,977	1,214,362
1922	1,009,139	540,153	1,548,292
1924	1,459,200	628,573	2,087,773

* Transactions of *World Power Conference*, Sectional Meeting, Basle, Switzerland, 1924, Vol. I, p. 248.

CONCLUSIONS

It is difficult to coordinate estimates of water power for the several countries, particularly estimates of potential water power, because of the differences in their elements and character and in the completeness and accuracy of the data on which they are based; but the estimates here given are considered sufficiently accurate to afford a rough idea of the potential water power of the world and the extent of its development. The figures for the developed water power represent the rated capacity of water wheels or turbines installed, and the figures for the potential power represent the total power that could be obtained at ordinary low water, including the power already developed. The installed capacity usually amounts to two or three times the power available at low water. Thus, although the potential power in the United States amounts to 35,000,000 horsepower and the capacity of the water wheels already installed is 11,700,000 horsepower, the inference should not be drawn that 33% of the water power resources of the country are developed. Probably with complete development the installed capacity would amount to 80,000,000 horsepower or more, and thus only about 15% of the total resources have been developed.

The figure for the developed water power in the United States includes only plants having a capacity of 100 horsepower or more and is based on excellent data. Even on this basis the capacity of constructed plants nearly equals the capacity of those in all Europe, for which the figures are presumed to include plants of all capacities, and at the present rate of increase this country will surpass Europe by a considerable margin in another three years.

In Table 31 the figures showing the potential power for the United States represent the power available 90% of the time at 70% efficiency.

TABLE 31

SUMMARY OF POTENTIAL AND DEVELOPED WATER POWER IN 1926, IN HORSEPOWER*

	Developed	Potential
North America:		
Mexico	300,000	6,000,000
United States	11,721,000	35,000,000
Alaska	43,000	1,000,000
Newfoundland	160,000	400,000
Canada	4,556,000	18,250,000
Costa Rica	15,000	1,000,000
Guatemala	4,000	1,500,000
Honduras	3,000	1,000,000
Nicaragua	400	800,000
Salvador	2,700	200,000
Panama	13,300	500,000
West Indies	19,350	150,000
Approximate Total	16,800,000	66,000,000
South America:		
Argentina	25,000	5,000,000
Bolivia	13,500	2,500,000
Brazil	500,000	25,000,000
British Guiana	.	2,500,000
Dutch Guiana	.	800,000
French Guiana		500,000
Chile	114,000	2,500,000
Columbia	25,000	4,000,000
Ecuador	5,500	1,000,000
Paraguay	200	2,000,000
Peru	55,000	4,500,000
Uruguay		300,000
Venezuela	13,000	3,000,000
Approximate Total	750,000	54,000,000
Europe:		
Sweden	1,350,000	8,000,000
Norway	1,900,000	9,500,000
Finland	220,000	1,800,000
Russia	230,000	3,000,000
Estonia	16,950	125,000
Latvia, Lithuania	5,000	100,000
Poland	90,000	1,400,000
Ukraine	40,000	425,000
Region of the Caucasus	5,000	5,000,000
Hungary	3,000	175,000
Czechoslovakia	155,000	1,000,000

* Mimeographed Release of the U. S. Geological Survey, December 19, 1927.

TABLE 31 (*Continued*)

SUMMARY OF POTENTIAL AND DEVELOPED WATER POWER IN 1926, IN HORSEPOWER

	Developed	Potential
Jugoslavia	180,000	3,000,000
Austria	325,000	1,660,000
Rumania	30,000	1,600,000
Bulgaria	18,000	1,200,000
Greece	8,000	250,000
Turkey		Small
Albania	1,000	500,000
Italy	2,300,000	3,800,000
Switzerland	1,850,000	2,500,000
Germany	1,100,000	2,000,000
France	2,000,000	5,400,000
British Isles	250,000	850,000
Belgium	700	Small
Denmark	11,000	9,000
Netherlands	150	Small
Spain	1,000,000	4,000,000
Portugal	10,000	300,000
Iceland		500,000
Approximate Total	13,100,000	58,000,000
Asia:		
Chinese Republic	1,650	20,000,000
India	200,000	27,000,000
Asia Minor	500	500,000
Arabia		
Persia		200,000
Afghanistan	2,000	500,000
Siberia	90,800	8,000,000
French Indo-China		4,000,000
Siam and Malay States	4,500	4,000,000
Chosen	18,300	500,000
Japan	1,750,000	4,500,000
Approximate Total	2,100,000	69,000,000
Africa:		
Tangier		50,000
Morocco		250,000
Algeria	130	200,000
Tunisia		30,000
Tripoli		Small
Eritrea		Small
British Somali		Small
Italian Somali		Small
Gold Coast and British mandate in Togo		1,450,000

TABLE 31 (*Continued*)

SUMMARY OF POTENTIAL AND DEVELOPED WATER POWER IN 1926, IN HORSEPOWER

	Developed	Potential
Liberia	......	4,000,000
Sierra Leone	......	1,700,000
Senegal	......	250,000
Rio de Oro	......	Small
Gambia	......	Small
Portuguese Guinea	......	Small
Union of South Africa	5,000	1,600,000
Angola	4,000	4,000,000
Southwest Africa (Union of South Africa mandate)	......	150,000
Belgian Congo and Belgian mandate	250	90,000,000
French Congo	......	35,000,000
French mandate in Cameroon	......	13,000,000
Nigeria and British mandate in Cameroon	......	9,000,000
Rhodesia	2,500	2,500,000
Tanganyika (British mandate)	800	2,700,000
British Central Africa	......	1,200,000
British East Africa	900	4,700,000
Portuguese East Africa	......	3,700,000
Bechuanaland	......	20,000
Abyssinia	......	4,000,000
Egypt	......	600,000
Ivory Coast, Dahomey, and French mandate in Togo	......	2,850,000
French Guinea	......	2,000,000
French Sudan	......	1,000,000
Madagascar	100	5,000,000
Approximate Total	14,000	190,000,000
Oceania:		
Australia	2,000	600,000
New Zealand	60,000	2,500,000
Philippine Islands	......	1,500,000
Sumatra	20,000	2,000,000
Java	60,000	750,000
Borneo, including New Guinea and Papua	......	7,500,000
Tasmania	75,000	700,000
Celebes	500	1,000,000
Hawaii	25,000	100,000
Approximate Total	240,000	17,000,000

TABLE 31 (*Continued*)

SUMMARY OF POTENTIAL AND DEVELOPED WATER POWER IN 1926, IN HORSEPOWER

	Developed	Potential
Recapitulation:		
North America	16,800,000	66,000,000
South America	750,000	54,000,000
Europe	13,100,000	58,000,000
Asia	2,100,000	69,000,000
Africa	14,000	190,000,000
Oceanica	240,000	17,000,000
Approximate Total	33,000,000	454,000,000

APPENDIX

DEVELOPED WATER POWER IN THE UNITED STATES JANUARY 1, 1927

THE Department of the Interior, through the Geological Survey, reports that the developed water power of the United States in plants of 100 horsepower or more was 11,721,000 horsepower on January 1, 1927, an increase of 544,000 horsepower, or about 5%, during 1926. The figures for several recent years, as determined by the Geological Survey, are as follows:

1921 November.... 7,926,958	1926 January 1....11,176,596
1924 March....... 9,086,958	1927 January 1 ..11,720,938
1925 March 10,037,655	

The following table shows the distribution of the developed water power in the United States by sections and in a general way the important water power regions of the country, and for each state and group of states the total capacity of water wheels in plants of 100 horsepower or more and the capacity in public utility and manufacturing plants.

TABLE 32

DEVELOPED WATER POWER IN THE UNITED STATES JANUARY 1, 1927*

(Plants of 100 horsepower or more)

DIVISION AND STATE	TOTAL		PUBLIC UTILITY AND MUNICIPAL		MANUFACTURING AND MISCELLANEOUS	
	No of Plants	Capacity in H.p.	No of Plants	Capacity in H p	No of Plants	Capacity in H p
United States	3,390	11,720,983	1,565	9,961,202	1,825	1,759,781
New England	1,221	1,535,468	264	779,449	957	756,019
Middle Atlantic	613	2,055,853	239	1,757,413	374	298,440
East North Central	369	1,009,915	250	770,424	119	239,491
West North Central	201	532,894	150	436,450	51	96,444
South Atlantic	341	1,841,197	161	1,600,339†	180	240,858
East South Central	60	867,638	45	863,681	15	3,957
West South Central	29	32,333	18	28,828	11	3,505
Mountain	245	1,030,224	196	1,010,743	49	19,481
Pacific	311	2,815,461	242	2,713,875	69	101,586
New England						
Maine	250	525,509	78	222,570	172	302,939
New Hampshire	244	277,252	62	143,711	182	133,541
Vermont	196	200,157	66	156,501	130	43,656
Massachusetts	348	353,939	33	171,977	315	181,962
Rhode Island	59	30,188	5	3,285	54	26,903
Connecticut	124	148,423	20	81,405	104	67,018

(Continued on next page)

* Prepared by the Geological Survey of the Department of the Interior and by the Federal Power Commission

† Two plants with total of about 140,000 horsepower considered manufacturing plants in previous reports allocated to public utilities in this report

TABLE 32 (*Continued*)

DEVELOPED WATER POWER IN THE UNITED STATES JANUARY 1, 1927

DIVISION AND STATE	TOTAL		PUBLIC UTILITY AND MUNICIPAL		MANUFACTURING AND MISCELLANEOUS	
	No of Plants	Capacity in H p.	No of Plants	Capacity in H.p	No of Plants	Capacity in H p.
Middle Atlantic.						
New York	529	1,757,355	186	1,474,100	343	283,255
New Jersey	34	18,902	10	8,658	24	10,244
Pennsylvania	50	279,596	43	274,655	7	4,941
East North Central						
Ohio	24	30,320	16	25,236	8	5,084
Indiana	24	56,156	16	52,341	8	3,815
Illinois	31	94,202	16	77,277	15	16,925
Michigan	128	355,261	108	307,080	20	48,181
Wisconsin	162	473,976	94	308,490	68	165,486
West North Central						
Minnesota	69	274,589	47	196,271	22	78,318
Iowa	49	179,580	40	177,980	9	1,600
Missouri	7	20,560	5	20,260	2	300
North Dakota	1	245			1	245
South Dakota	9	19,671	5	7,050	4	12,621
Nebraska	43	21,335	38	20,532	5	803
Kansas	23	16,914	15	14,357	8	2,557
South Atlantic.						
Delaware	3	1,161	..	.	3	1,161
Maryland	15	37,875	4	33,825	11	4,050
District of Columbia	2	1,350			2	1,350
Virginia	62	138,046	32	96,432	30	41,614
West Virginia	12	91,279	7	81,174	5	10,105
North Carolina	122	542,618	47	410,556	75	132,062
South Carolina	59	571,428	32	543,321	27	28,107
Georgia	62	448,670	36	426,381	26	22,289
Florida	4	8,770	3	8,650	1	120
East South Central						
Kentucky	6	34,255	3	33,351	3	904
Tennessee	31	174,175	24	172,920	7	1,255
Alabama	23	659,208	18	657,410	5	1,798
Mississippi	.	.	.		. .	
West South Central						
Arkansas	4	15,550	4	15,550		
Louisiana		...		.		
Oklahoma	4	1,948	4	1,948		.
Texas	21	14,835	10	11,330	11	3,505
Mountain						
Montana	31	376,040	29	374,100	2	1,940
Idaho	52	320,097	45	317,095	7	3,002
Wyoming	10	10,480	9	10,154	1	326
Colorado	60	95,554	32	84,401	28	11,153
New Mexico	7	1,808	7	1,808		
Arizona	9	59,360	9	59,360		
Utah	67	153,435	57	150,675	10	2,760
Nevada	9	13,450	8	13,150	1	300
Pacific						
Washington	75	656,722	68	630,590	7	26,132
Oregon	82	241,759	47	185,387	35	56,372
California	154	1,916,980	127	1,897,898	27	19,082
Outlying Possessions.						
Alaska		40,000*				
Hawaii		32,224				
Porto Rico		15,000*				

* 1925, figures for 1927 not available

TABLE 33

DISTRIBUTION OF ACTIVE APPLICATIONS BEFORE THE FEDERAL POWER COMMISSION, BY STATES, TO JUNE 30, 1927*

State	Number of Applications	Gross Horsepower (no deductions made for conflicting applications) Primary	Established Installed Capacity
Alabama	9	266,160	951,800
Alaska	30	121,729	134,231
Arizona	28	9,284,550	13,034,700
Arkansas	3	217,000	511,000
California	140	1,830,440	4,080,575
Colorado	28	129,136	248,305
Connecticut	1	7,400	49,800
District of Columbia	2	47,300	50,000
Florida	4	27,162	111,700
Georgia	4	75,520	214,000
Idaho	37	89,731	184,935
Illinois	5	49,902	81,340
Indiana	3	12,550	29,200
Kentucky	10	269,300	689,000
Maine	1	250,000	650,000
Maryland	1	44,700	594,000
Michigan	3	3,218	10,000
Minnesota	7	30,310	76,440
Missouri	5	88,700	321,000
Mississippi	1	.	.
Montana	26	179,041	276,331
Nevada	4	.	.
New Mexico	2	1,180	51,880
New York	9	3,923,370	5,133,890
North Carolina	4	27,017	110,880
Ohio	3	1,110	1,350
Oklahoma	1	1,700	11,000
Oregon	27	390,388	829,303
Pennsylvania	6	81,600	331,500
South Carolina	3	127,040	420,400
South Dakota	3	1,185	2,265
Tennessee	10	1,226,080	2,218,000
Utah	18	762,499	1,127,090
Virginia	6	63,276	210,000
Washington	24	730,094	1,378,800
West Virginia	6	131,068	598,000
Wisconsin	4	32,957	57,337
Wyoming	5	1,360	2,679
Total	483	20,525,773	34,782,831

NOTE No active projects are at present before the commission in the following states Delaware, Iowa, Kansas, Louisiana, Massachusetts, New Hampshire, New Jersey, North Dakota, Rhode Island, Texas, and Vermont.

* *Seventh Annual Report of the Federal Power Commission*, 1927, p. 19.

TABLE 34

POTENTIAL WATER POWER RESOURCES OF THE UNITED STATES*

STATE AND DIVISION	AVAILABLE 90% OF THE TIME		AVAILABLE 50% OF THE TIME	
	Horsepower	Percentage	Horsepower	Percentage
United States	34,818,000	100 00	55,030,000	100 00
New England	998,000	2 87	1,978,000	3 60
Middle Atlantic	4,317,000	12 40	5,688,000	10 35
East North Central	737,000	2 12	1,391,000	2 53
West North Central	871,000	2 50	1,844,000	3 35
South Atlantic	2,476,000	7 11	4,464,000	8 11
East South Central	1,011,000	2 90	2,004,000	3 64
West South Central	434,000	1 25	888,000	1 61
Mountain	10,736,000	30 83	15,513,000	28 19
Pacific	13,238,000	38 02	21,260,000	38 63
New England				
Maine	536,000	1 54	1,074,000	1 95
New Hampshire	186,000	53	350,000	64
Vermont	80,000	23	169,000	31
Massachusetts	106,000	31	235,000	43
Rhode Island	25,000	07	40,000	07
Connecticut	65,000	19	110,000	20
Middle Atlantic				
New York	4,010,000	11 52	4,960,000	9 03
New Jersey	50,000	14	90,000	16
Pennsylvania	257,000	74	638,000	1 16
East North Central				
Ohio	55,000	16	166,000	30
Indiana	40,000	12	110,000	20
Illinois	189,000	54	361,000	66
Michigan	168,000	48	274,000	50
Wisconsin	285,000	82	480,000	87
West North Central				
Minnesota	203,000	58	401,000	73
Iowa	169,000	49	395,000	72
Missouri	67,000	19	152,000	27
North Dakota	82,000	23	193,000	35
South Dakota	63,000	18	110,000	20
Nebraska	183,000	53	342,000	62
Kansas	104,000	30	251,000	46
South Atlantic				
Delaware	5,000	01	10,000	02
Maryland and District of Columbia	106,000	30	238,000	43
Virginia	459,000	1 32	812,000	1 48
West Virginia	355,000	1 02	980,000	1 78
North Carolina	540,000	1 55	816,000	1 48
South Carolina	429,000	1 23	632,000	1 15
Georgia	572,000	1 65	958,000	1 74
Florida	10,000	03	18,000	03
East South Central				
Kentucky	77,000	22	184,000	33
Tennessee	432,000	1 24	710,000	1 29
Alabama	472,000	1 35	1,050,000	1 91
Mississippi	30,000	09	60,000	11
West South Central				
Arkansas	125,000	36	178,000	32
Louisiana	1,000	00	2,000	00
Oklahoma	70,000	20	194,000	35
Texas	238,000	69	514,000	94

* U. S. Geological Survey, 1924.

Table 34 *(Continued)*

Potential Water Power Resources of the United States

State and Division	Available 90% of the Time: Horsepower	Available 90% of the Time: Percentage	Available 50% of the Time: Horsepower	Available 50% of the Time: Percentage
Mountain				
Montana	2,550,000	7 32	3,700,000	6 72
Idaho	2,122,000	6 10	4,032,000	7 33
Wyoming	704,000	2 02	1,182,000	2 15
Colorado	765,000	2 20	1,570,000	2 85
New Mexico	116,000	33	186,000	34
Arizona	2,759,000	7 92	2,887,000	5 25
Utah	1,420,000	4 08	1,586,000	2 88
Nevada	300,000	86	370,000	67
Pacific				
Washington	4,970,000	14 27	7,871,000	14 30
Oregon.	3,665,000	10 53	6,715,000	12 20
California	4,603,000	13 22	6,674,000	12 13
Outlying Possessions				
Alaska	1,000,000		2,500,000	
Porto Rico	19,000		28,000	.
Hawaii	100,000	...	200,000	..

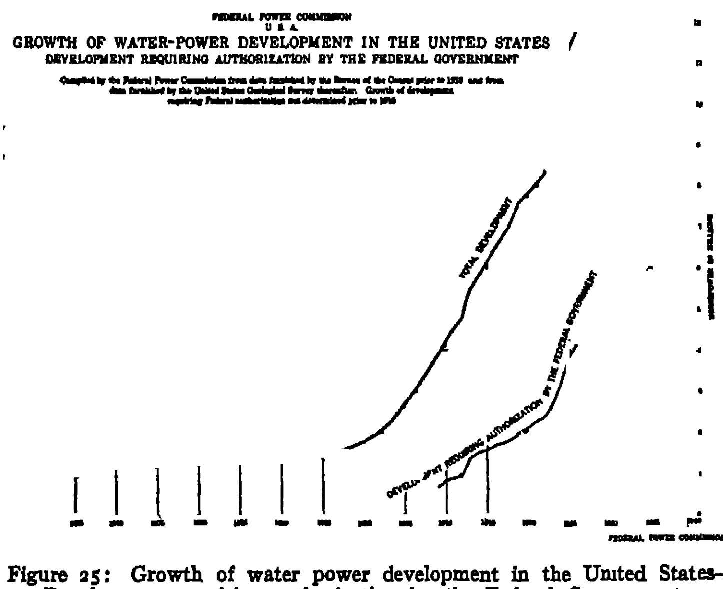

Figure 25: Growth of water power development in the United States—Development requiring authorization by the Federal Government

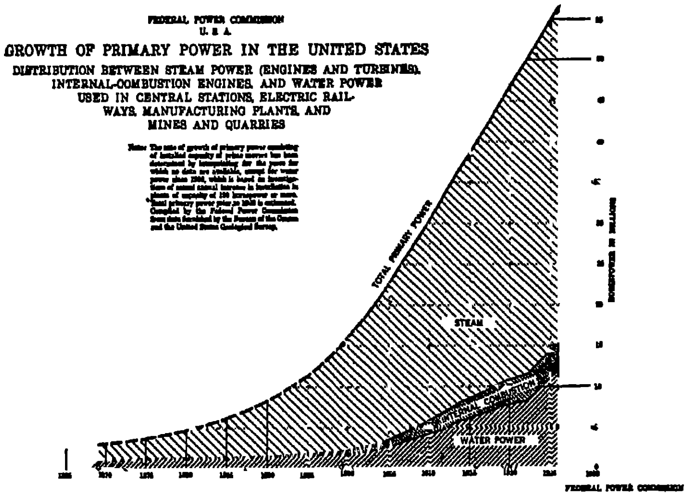

Figure 26. Growth of primary power in the United States

TABLE 35

DISTRIBUTION OF CENTRAL STATION ENERGY, 1913 TO 1926*

Year	Total Energy Generated (Kw. Hr)	Estimated Net Consumption by Customers (Kw Hr.)				Line Losses and Intra-Company Business (Kw. Hr)
		Total	Lighting	Power	Railways	
1913	13,000,000,000	10,500,000,000	2,800,000,000	4,400,000,000	3,300,000,000	2,500,000,000
1914	14,400,000,000	11,620,000,000	2,900,000,000	5,370,000,000	3,350,000,000	2,780,000,000
1915	16,175,000,000	13,055,000,000	3,000,000,000	6,055,000,000	4,000,000,000	3,120,000,000
1916	21,230,000,000	17,130,000,000	3,580,000,000	9,450,000,000	4,100,000,000	4,100,000,000
1917	25,438,000,000	20,528,000,000	4,250,000,000	11,878,000,000	4,400,000,000	4,910,000,000
1918	29,200,000,000	23,570,000,000	5,200,000,000	13,870,000,000	4,500,000,000	5,630,000,000
1919	34,900,000,000	28,160,000,000	6,250,000,000	17,310,000,000	4,600,000,000	6,740,000,000
1920	39,518,903,000	31,898,903,000	7,580,000,000	19,498,903,000	4,820,000,000	7,620,000,000
1921	36,970,697,000	29,830,697,000	8,500,000,000	16,730,697,000	4,600,000,000	7,140,000,000
1922	43,559,677,000	35,159,677,000	9,298,000,000	20,219,677,000	5,642,000,000	8,400,000,000
1923	51,132,883,000	41,490,535,000	11,200,000,000	24,290,535,000	6,000,000,000	9,642,348,000
1924	54,413,403,000	43,893,403,000	12,600,000,000	25,092,873,000	6,200,530,000	10,520,000,000
1925	61,158,857,000	49,354,857,000	13,476,000,000	29,577,857,000	6,301,000,000	11,804,000,000
1926	68,732,000,000	55,468,000,000	14,562,000,000	34,307,000,000	6,599,000,000	13,264,000,000

* *Electrical World*, January 2, 1926, p 7

TABLE 36

COAL PRODUCTION IN THE UNITED STATES, 1821-1925*
(In thousands of tons)

Year or Yearly Average	Quantity		
	Total	Anthracite	Bituminous
1821–1830	140	66	75
1831–1840	1,032	722	310
1841–1850	4,535	2,697	1,837
1851–1860	12,513	7,645	4,868
1861–1865	20,538	11,142	9,396
1866–1870	31,706	16,281	15,425
1871–1875	52,179	23,407	28,773
1876–1880	62,261	25,800	36,461
1881–1885	107,291	36,198	71,093
1886–1890	138,398	43,952	94,446
1891–1895	178,822	53,405	125,416
1896–1900	227,123	55,625	171,498
1901–1905	339,357	66,854	272,503
1906–1910	454,555	81,142	373,413
1911–1915	529,189	89,233	439,955
1916–1920	626,386	92,741	533,645
1921	506,395	90,473	415,922
1922	476,951	54,683	422,268
1923	657,904	93,339	564,565
1924	571,613	87,927	483,687
1925	585,083	62,116	522,967
1926	.		578,290

* U. S Geological Survey, *Mineral Resources of United States*, 1926

TABLE 37

ESTIMATED COAL RESERVES OF THE UNITED STATES, EXCLUSIVE OF ANTHRACITE*

State	Lignite	Subbituminous	Bituminous	Semibituminous
Alabama			35,582,000,000	
Arkansas	60,000,000		90,700,000	854,800,000
Arizona		761,000,000	6,700,000	
California		7,000,000	18,000,000	
Colorado		69,430,000,000	141,980,000,000	
Georgia				300,000,000
Idaho		60,000,000	300,000,000	
Illinois			122,021,000,000	
Indiana			34,724,000,000	
Iowa			14,477,700,000	
Kansas			19,755,000,000	
Kentucky			81,561,000,000	
Maryland			1,005,000,000	4,094,700,000
Michigan			1,000,000,000	
Missouri			42,000,000,000	
Montana	200,000,000,000	32,000,000,000	1,895,000,000	
New Mexico		115,250,000,000	11,840,000,000	
North Carolina			56,000,000	
North Dakota	400,000,000,000		61,272,000,000	
Ohio			31,171,000,000	4,000,000,000
Oregon		3,000,000,000	1,500,000,000	
Pennsylvania			35,230,800,000	8,624,980,000
South Dakota	400,000,000			
Tennessee			16,886,000,000	
Texas	15,300,000,000		5,941,000,000	
Utah		2,500,000,000	64,080,000,000	
Virginia			19,050,000,000	264,500,000
Washington		26,000,000,000	7,484,000,000	
West Virginia			94,214,000,000	18,764,000,000
Wyoming		393,160,000,000	53,563,000,000	
Totals	615,760,000,000	642,168,000,000	898,703,900,000	36,902,980,000

* Adapted from Table VIII, page 644, of the *Transactions of the First World Power Conference*, Vol I.

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